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AFRPL-TR-69-193

PACKAGE SYSTEM STORABILITY TEST ARTICLE

Fred A. Fujimoto
Convair division of General Dynamics

TECHNICAL REPORT AFRPL-TR-69-193
August 1969

Air Force Rocket Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Edwards Air Force Base, California

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PACKAGE SYSTEM STORABILITY
TEST ARTICLE

Fred A. Fujimoto

FOREWORD

The work documented in this final report was accomplished by the Convair division of General Dynamics, San Diego, California, under USAF Contract No. AF04611-68-C-0052 during the period from April 1968 to July 1969. The work was administered under the direction of the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California, by 1st Lt, Richard B. Mears, USAF/RPRPT, Project Officer.

This report was submitted in July 1969 for approval under contractor's identification number GDC 512-2-41.

Convair division of General Dynamics performed the work on the contract under the administration of Mr. W. H. Shaefer, Chief of Structural Design, with F. A. Fujimoto as Project Leader, G. F. Foelsch, Chief of Structural Analysis, M. S. Hersh as Metallurgist, R. M. Anderson as Test Engineer, R. Bruce as the Production Engineer, and G. D. Lundquist as the Weld Engineer.

This technical report has been reviewed and approved:

Lt. Richard B. Mears
USAF/RPRT
Air Force Rocket Propulsion Laboratory
Edwards Air Force Base

ABSTRACT

This report presents the design, manufacture, testing, and delivery of 15-gallon tanks for subsequent use by the Air Force Rocket Propulsion Laboratory in their long-term propellant tankage storability program. A total of 12 tanks, 6 each of materials 6Al-4V ELI titanium alloy and X-2021-T62 aluminum alloy, was delivered to the Air Force Rocket Propulsion Laboratory. Six tanks, three of each material, were cleaned for nitrogen tetroxide (N_2O_4) and the remaining six were cleaned for hydrazine propellant testing. Tensile coupons, both welded and unwelded, from each sheet material used in the tank fabrication were delivered to assist in correlating vessel storability performance.

The tank configuration, consisting of two ellipsoidal bulkheads ($a/b = \sqrt{2}$), is 18 inches in diameter with a cylinder length of 5.4 inches and includes an inlet and outlet for propellant loading, pressurization, and draining. The tanks were designed for an operating pressure of 100 psig with a minimum factor of safety of 1.5 based on yield. Fabrication processing, including welding, quality control, inspection requirements, and proof testing, was representative of actual production tank processing. Tank welding was accomplished by electron beam (EB) welding.

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SECTION I

INTRODUCTION

The Air Force Rocket Propulsion Laboratory (AFRPL) is conducting a long-term (5 to 10 years) storability evaluation of tankage material, components, and integrated propulsion feed systems with current and advanced storable propellants. The program was initiated to go beyond coupon compatability testing to obtain a more realistic evaluation of materials and systems used with storable liquid propellants and to simulate as closely as possible the life cycle of hardware and materials used in missile systems. Currently manufactured hardware, including tankage material, cannot be duplicated in test specimens. Such conditions as the bi-axial stress, manufacture, and quality control process, cleaning procedures, production variables, etc., are typical.

During the past several years the Air Force Rocket Propulsion Laboraty has procured various individual components and systems required for this evaluation. This contract (1) provided for the design, fabrication, and test of twelve 15-gallon tanks for inclusion in the storability evaluation. The tanks, six of material 6A1-4V titanium alloy and six of X-2021 experimental aluminum alloy, were designed and fabricated using standard aerospace manufacturing and inspection procedures. The tanks were subjected to the same detail design features, fabrication processes, welding procedures, quality control and inspection requirements, structural acceptance tests, and leakage evaluation as would be imposed upon production tanks.

The long-term storability evaluation of tankage and propellants requires a detail knowledge of the article throughout its life to result in useful analysis of the material performance. Chemicals used for cleaning the material during manufacture, heat treatment used, x-ray and dye penetrant inspection, welding procedures, and quality control standards may affect tankage performance. This report summarizes the detail design, manufacturing process, inspection, and testing accomplished on the delivered tanks.

SECTION II

TANK DESIGN

2.1 DESIGN APPROACH

The tank design approach was based on using existing ellipsoidal bulkhead form dies employed under a similar contract(2) that contained many of the design features specified under this contract. The design was updated to include the influences of the 6Al-4V titanium alloy and X-2021 experimental aluminum alloy, the electron beam (EB) welding process, and the tank fill and drain fittings desired.

2.2 DESIGN CRITERIA

The tank design was based on the criteria of providing a propellant storage container with an internal volume of 15 gallons plus 5 gallons with a cylinder length-to-diameter ratio of 1.0 to 2.0 and capable of withstanding internal pressures of:

Operating Pressure:	100 psig
Proof Pressure:	150 psig
Burst Pressure:	200 psig

The pressure loadings specified are aligned to specifications applicable to removable liquid propellant tanks for post-boost propulsion systems as specified in MIL-T-5208A (ASG). These loading conditions are:

Proof — Maximum operating pressure times 1.5 without yielding, applied under 1g loading conditions.

Burst — Proof pressure times 1.33 under 1g loading conditions.

The proof loading condition is aligned to yield stress and the ultimate loading condition to ultimate stress. Whichever is critical determines the analytical stresses dependent upon the weld strength of the specific material.

The propellants considered for storage were: nitrogen tetroxide (N_2O_4), chlorine pentafluoride (ClF_5), and hydrazine fuel.

The tanks were manufactured using the EB weld process and have a system of part number serialization so that correlation of test coupon sheet and vessel parts can be made.

The tanks have an MS 27850 type fitting installation, built to Specification MIL-F-27417, for loading, pressurizing, and draining propellants.

Tankage material was specified to be:

- X-2021 Experimental Aluminum Alloy — 6 Tanks
- 6Al-4V Titanium Alloy — 6 Tanks

2.3 DETAIL DESIGN

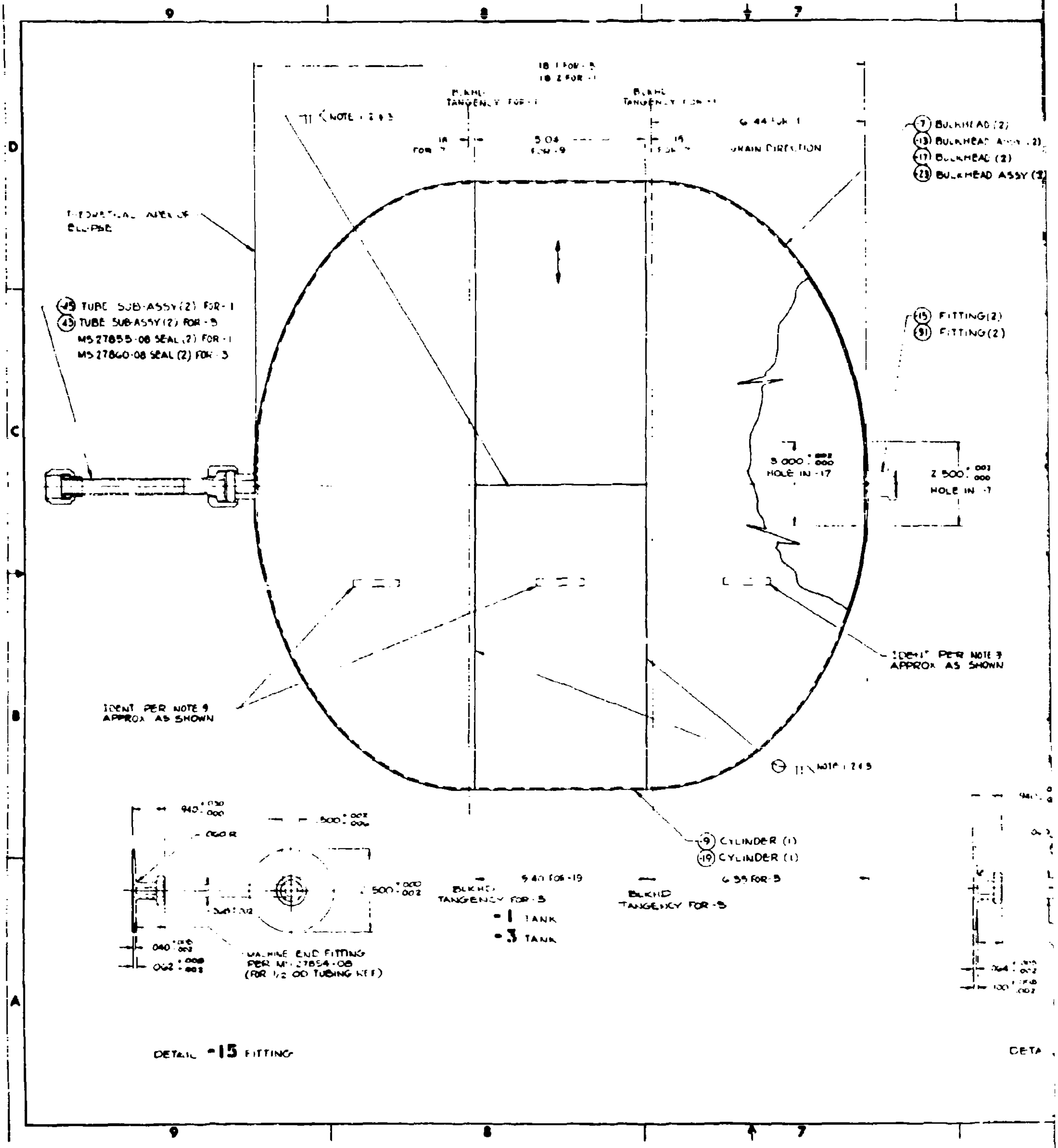
The tank detail design was based on using an existing ellipsoidal bulkhead form die capable of producing a single-piece hydroformed bulkhead for both the aluminum and titanium tanks. The aluminum material was cold formed in a single draw operation. The titanium material was cold formed in three draw operations with intermediate anneals.

The tank geometry, ellipsoidal bulkheads $(a/b = \sqrt{2})$, 18 inches in diameter with a cylinder length of 5.4 inches, Figure 1, provides tank capacity of 15.27 gallons for the aluminum-alloy tanks and 15.72 gallons for the titanium-alloy tanks. The titanium tanks are slightly larger in diameter (0.18-inch ID larger) than the aluminum-alloy tanks as a result of the encapsulation material (body steel) required in the forming and intermediate anneal operation. The titanium alloy was encapsulated to prevent oxygen and hydrogen embrittlement of the base material during the re-anneal operation.

The skin gages are 0.064 inch for the X-2021 experimental aluminum alloy and 0.040 for the 6Al-4V titanium alloy. These gages were selected based on availability and manufacturing requirements respectively. The 0.064-inch X-2021 aluminum alloy was the only sheet thickness available as a warehouse stock item. The 0.040 6Al-4V ELI titanium gage was based on the difficulty of hydroforming thin-gage titanium alloy and obtaining satisfactory dimensional control over the circumferential length to match the corresponding cylinder section.

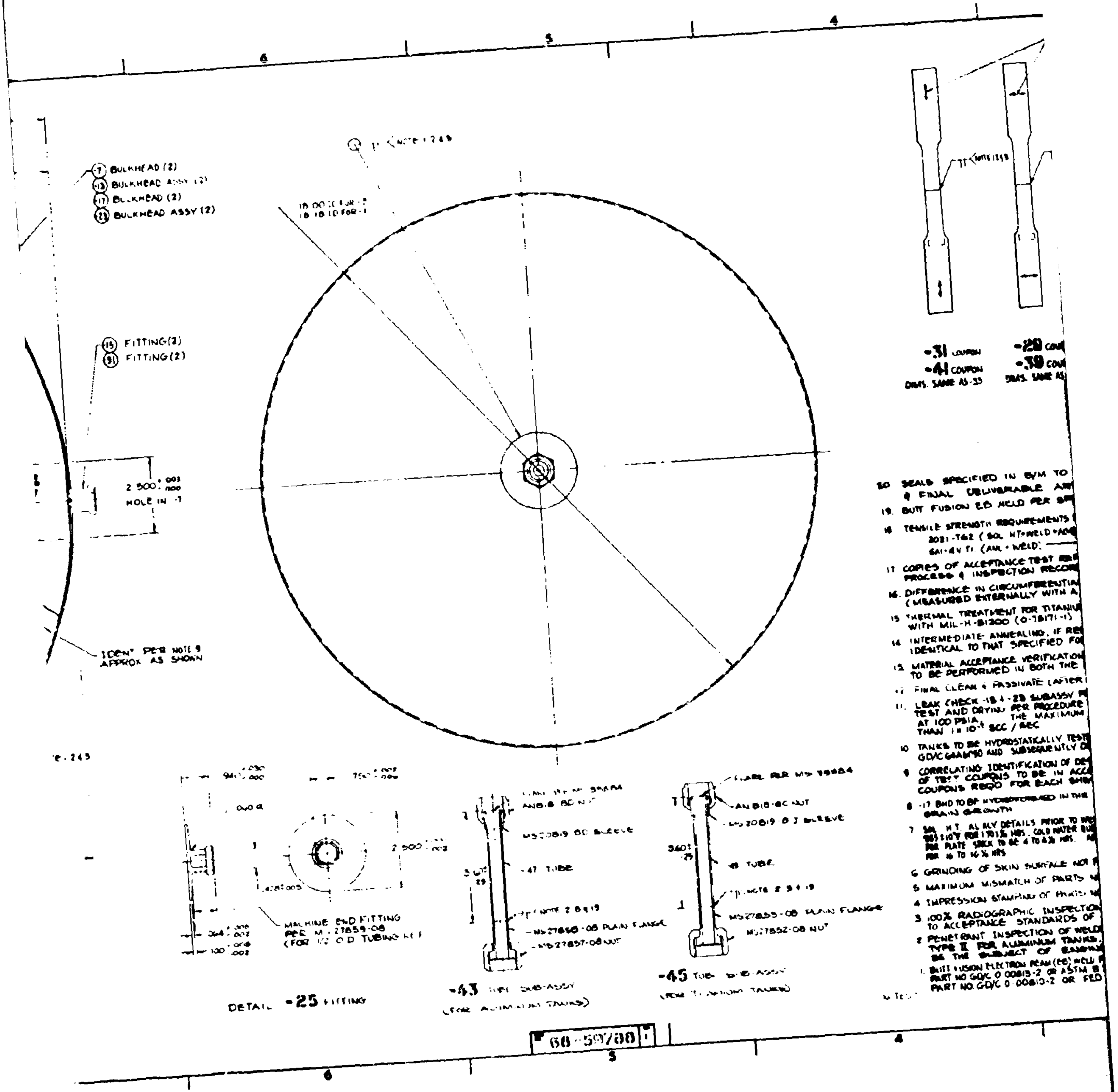
Membrane stress at an operating pressure of 100 psig is 14,000 psi and 22,500 psi for the aluminum and the titanium alloy respectively. Including the effects of stress concentration and discontinuity stress at the circumferentia[illegible], ellipsoidal bulkhead weld joint stresses are 15,000 psi and 24,000 psi at operating pressure. Both are substantially below the stress corrosion "threshold" of 37,000 psi and 40,000 psi. (Threshold stress based on synthetic sea water stress corrosion cracking for X-2021,[3] and reported N_2O_4 stress corrosion cracking for 6Al-4V titanium.[4]) Margins of safety and detail stress analysis are presented in Appendix I.

The tank inlet and outlet ports, Convair division drawing 68-59788-15 titanium and 68-59788-51 aluminum fittings (Figure 1), were designed to use standard MS 27855-08 stainless steel and MS 27860-08 aluminum alloy "Bobbin" seals respectively. The -15 and -51 fittings were provided with wrenching flats for ease of assembly and disassembly of the fitting nut. The -51 fitting height was limited to one inch in design as a result of availability of the X-2021 aluminum alloy in one-inch plate stock only.



BULKHEAD (2)
BULKHEAD ASSY (2)
TUBE SUB-ASSY (2) FOR -1
TUBE SUB-ASSY (2) FOR -3
MS 27855-08 SEAL (2) FOR -1
MS 27860-08 SEAL (2) FOR -3
GRAIN DIRECTION
FITTING (2)
FITTING (2)
HOLE IN -17
2.500 HOLE IN -7
IDENT PER NOTE 9 APPROX AS SHOWN
IDENT PER NOTE 9 APPROX AS SHOWN
CYLINDER (1)
CYLINDER (1)
BLKHD TANGENCY FOR -3
BLKHD TANGENCY FOR -3
-1 TANK
-3 TANK
MACHINE END FITTING PER MS 27854-08 (FOR 1/2 OD TUBING REF)
DETAIL -15 FITTING

A



BULKHEAD (2)
BULKHEAD ASSY (2)
BULKHEAD (2)
BULKHEAD ASSY (2)
FITTING (2)
FITTING (2)
IDENT PER NOTE 9 APPROX AS SHOWN
-31 COUPON
-41 COUPON
DIMS. SAME AS-35
MACHINE END FITTING
MS20819-8C SLEEVE
-47 TUBE
-45 TUBE SUB-ASSY
DETAIL -25 FITTING
68-59788

3

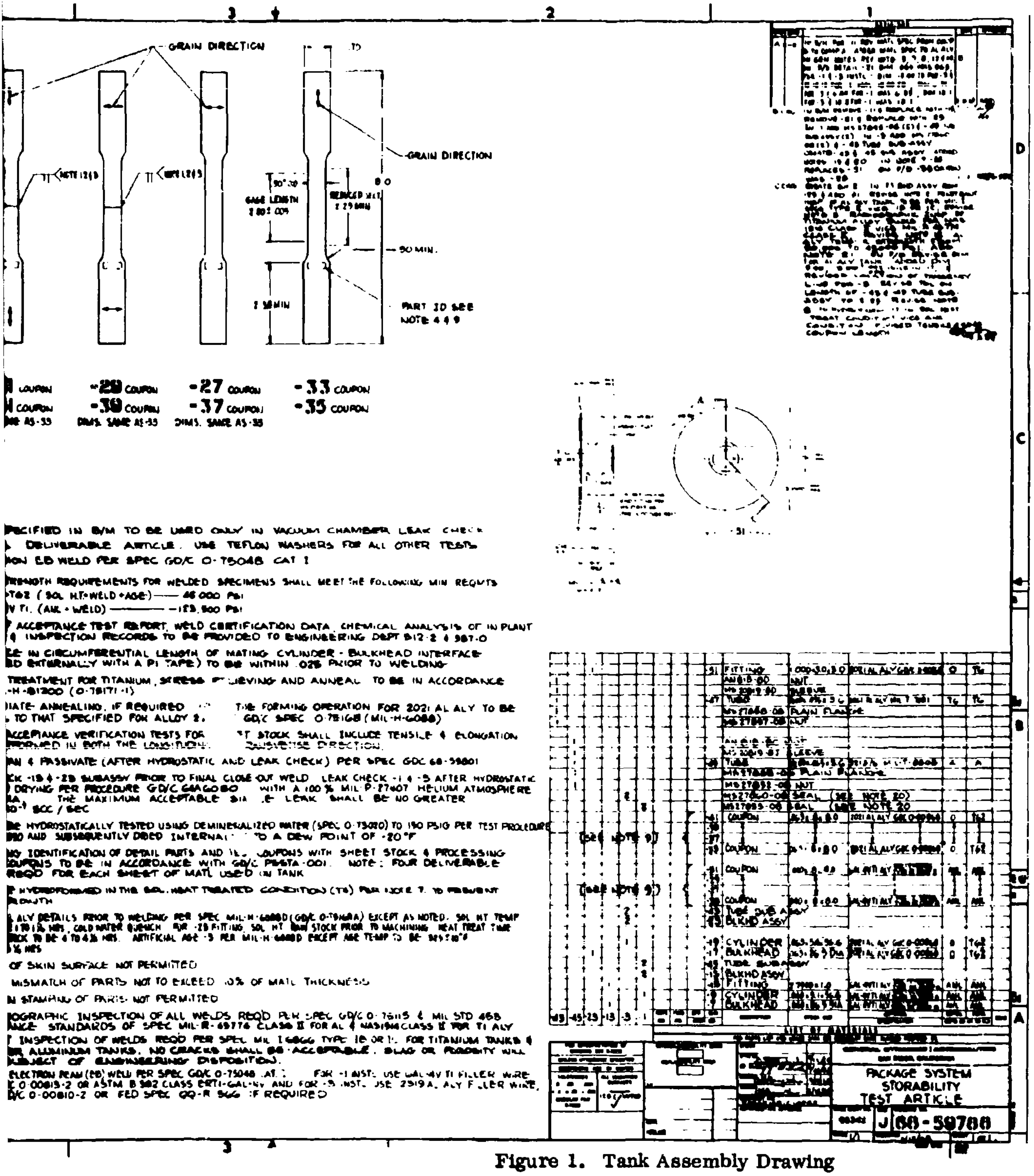


Figure 1. Tank Assembly Drawing

A fitting adapter was provided for each tank so that the tanks can be easily connected to the storage facility manifold. The adapter consists of a one-half inch tube flared at one end with a standard "AN" nut and sleeve and a plain MS flange at the other end to mate with the tank fittings.

2.4 MATERIAL

The AFRPL has specified the materials for the tanks in their Tank Storability Program. They are: X-2021 aluminum alloy (six tanks) and 6Al-4V titanium alloy (six tanks).

The X-2021 aluminum alloy is an experimental alloy developed by Alcoa for a program initiated by Marshall Spaceflight Center under Contract NAS8-5452. This program was aimed to develop a higher strength weldable aluminum alloy with good cryogenic toughness. X-2021 was one of the most promising alloys resulting from this development contract. This material is an aluminum-copper alloy identical in chemical composition to 2219 except for the presence of cadmium (0.05 - 0.20) and tin (0.03 - 0.08).

The 6Al-4V titanium alloy is a high alpha low beta composition with the total alloy content closely controlled to give good annealed strength. This material is double-melted by the consumable electrode method to control the interstitial additions. Both meltings are accomplished under vacuum to minimize contamination by oxygen, nitrogen, and hydrogen. The ELI grade of titanium contains a maximum of 0.13 percent oxygen and is used for applications that require maximum toughness-strength ratio such as cryogenic tankage and submarine hulls. The alloy is noted for its toughness and strength over a wide range of temperatures, its weldability, and its utility in pressure vessel applications.

2.4.1 <u>MATERIAL PROCUREMENT</u>. The 6Al-4V titanium alloy ELI grade in 0.040- by 36- by 96-inch sheet, seven sheets, was procured to MIL-T-9046F, Type III, Composition D. The bar stock 2-3/4 inches diameter by 20 inches long was procured to MIL-T-9047D, Type III, Composition A. The 0.040-inch titanium ELI grade is a standard stock item and is readily available from warehouse stock. The bar stock, 2-3/4-inch diameter in the ELI grade MIL-T-9047 Composition III, Type B or 1-inch-thick plate stock, was not available from warehouse stock. A survey of the mills revealed that a delay of up to 16 to 20 weeks is required to obtain a mill run. To preclude unreasonable delay the titanium bar stock was ordered to the Composition A with the oxygen content as close to the ELI grade as available in warehouse stock. The maximum O_2 content for ELI grade is 0.13. The bar stock received had an O_2 content of 0.14. All other chemical composition were within the ELI military specification requirements.

The mechanical properties of the sheet and bar material as shown in the military specifications are:

a. Sheet and plate per MIL-T-9046F, Type III Composition D (ELI)

130,000 psi minimum tensile strength
120,000 psi minimum yield strength
10% minimum elongation

b. Bar per MIL-T-9047D, Type III Composition A

130,000 psi minimum tensile strength
120,000 psi minimum yield strength
10% minimum elongation

The chemical analysis and room temperature mechanical properties test of the material procured for this program is given in Table I along with the size and quantity. The material conforms to military specification requirements for mechanical properties and chemical analysis.

The X-2021 aluminum alloy is in the early stages of development and limited in quantity, gage thickness and size. Available material in warehouse stock was gages of 0.064-, 0.25-, 0.50- and 1.00-inch-thick stock in limited quantity and temper. (X-2021 T8E31 for sheet stock and as fabricated "F" condition for the plate stock.) The sheet material, 0.064 by 36 by 96 inches was annealed and designated experimental X-2021-O aluminum alloy by Alcoa prior to shipment. The plate stock, 1.0 by 36 by 96 inches, was annealed from the "F" as fabricated condition to "O" temper and designated experimental X-2021-O plate prior to shipment.

The sheet (0.064 inch) and plate (1.00 inch) were ordered from Alcoa to their specifications for chemical and physical properties and with the following provisions:

a. Quality assurance provisions per Section 4 of Specification MIL-A-8920A.

b. Mechanical property limits of Table II of MIL-A-8920A apply.

c. In addition to chemical composition limits of MIL-A-8920A Table I, the limits of 0.05 - 0.20 cadmium and 0.03 - 0.08 tin apply.

d. Mechanical property limits of "O" temper sheet and plate are:

32,000 psi maximum tensile
16,000 psi maximum yield
12% minimum elongation

T-62 Temper:

69,000 psi minimum tensile
59,000 psi minimum yield
5% minimum elongation (sheet)
3% minimum elongation (plate)

Table I. Chemical Analysis and Mechanical Properties of 6Al-4V Titanium Alloy "As Received"

Gage/Size (in.)	0.040 × 36 × 96	2-3/4 Dia. × 20
Quantity (lb)	218	19
Supplier	TMCA	TMCA
Heat No.	G-4955	G-4162
Specification	MIL-T-9046F, Type III Comp D	MIL-T-9047D, Type III Comp A
Tensile Strength		
Typical/Top	143,000/	/138,000
High/Middle	144,700/	/140,000
Low/Bottom	141,200/	/136,500
Yield Strength		
Typical/Top	135,000/	/126,500
High/Middle	137,100/	/135,000
Low/Bottom	130,000/	/125,000
% Elongation		
Typical/Top	14/	/20
High/Middle	14/	/19
Low/Bottom	13/	/13
Chemistry (wt %)		
C	0.025	0.024
FE	0.09	0.14
N	0.011	0.008
AL	6.1	6.4
VA	4.1	4.0
H	0.005	0.005
O_2	0.09	0.14

e. The composition limits of X-2021 to be supplied but not to be the actual limits of the specific material shipped. Normal test result limits and actual mechanical property limits for both "O" and T-62 tempers on both the sheet and plate to be supplied.

Significantly more plate material was purchased than originally anticipated due to the minimum order specified by the vendor. Whereas a plate size of 36 by 32 inches is more than adequate for this program, the minimum order is a plate size 36 by 96 inches. Ideally, a bar stock 2-3/4 inches in diameter by 30 inches long would more than adequately meet the fabrication requirements; however, availability of only plate and sheet stock precluded this consideration.

The chemical and mechanical properties of the as-received material are shown in Table I. The data shown are within the specification requirements.

The chemical and mechanical properties of the as-received material reported in the certification data are presented in Table II. The mechanical properties of the "O" condition shown are in closer agreement with the typical mechanical properties quoted in Alcoa Green Letter[5] rather than the ordering specification. These values are:

Tensile Ultimate	24,000 psi
Tensile Yield	10,000 psi
Percent Elongation in 2 inches	23

The reason for the difference is the availability of data at the time the material was ordered.

2.4.2 MATERIAL RECEIVING INSPECTION. The as-received titanium and aluminum alloy were visually examined for identification, surface finish, size, thickness, etc. prior to processing. No unusual scratches, discoloration, or corrosion was noted that precluded acceptance. The aluminum alloy sheet and plate were received in an oiled condition to prevent corrosion as specified in the receiving report. The as-received gages of the aluminum and titanium alloys are presented in Sections 3.3 and 3.4. In general, all sheet material tolerance was on the high side but was within acceptable limits.

Three longitudinal and transverse tensile specimen were taken from both materials and tested for strength and elongation. The tension tests were performed on a Tinius-Olson testing machine equipped with a continuous stress-strain recorder. A Tinius-Olson Model S-1 extensometer was used to measure elongation. The tensile specimens, Figure 2, were tested at room temperature.

The titanium alloy quality verification test results, Table III, compare favorably with the vendor certification results reported in Section 2.4.1. The results are well within the minimum requirements of MIL-T-9046.

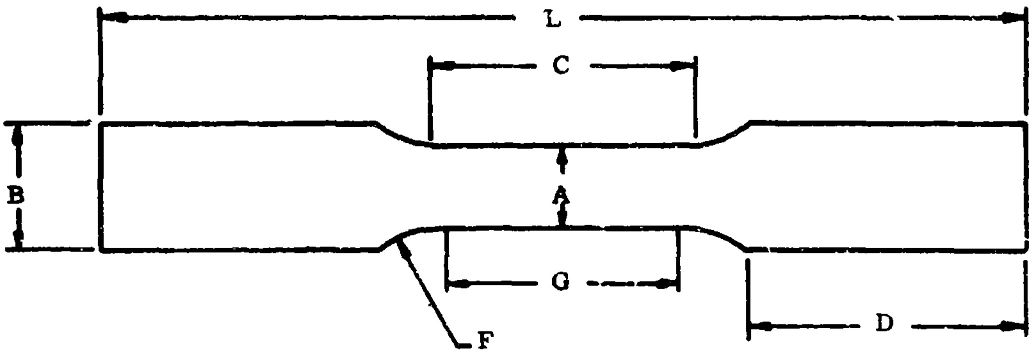
Table II. Chemical Analysis and Mechanical Properties of Bare X-2021-O Aluminum Alloy "As Received"

DESCRIPTION	SHEET		PLATE	
Size (in.)	0.064 × 36 × 96		1.00 × 36 × 96	
Quantity (lb)	146		376	
Supplier	Alcoa		Alcoa	
Lot No.	638 - 248		108 - 935	
Specification	*		*	
MECHANICAL PROPERTIES	Max	Min	Max	Min
Tensile Strength (ksi)	22.3	22.0	24.0	23.9
Yield Strength (ksi)	9.8	9.8	16.4	15.7
Elongation %	23.0	22.0	17.0	17.0

CHEMICAL COMPOSITION

Chemistry (Wt %)	(Max) Except as Noted	(Min)	
Silicon	0.20	--	
Iron	0.30	--	
Copper	6.8	5.8	
Manganese	0.40	0.20	
Magnesium	0.02	--	
Zirconium	0.25	0.10	
Zinc	0.10	--	
Titanium	0.10	0.02	
Vanadium	0.15	0.05	
Cadium	0.20	0.05	
Tin	0.08	0.03	
Other	0.05 each	0.15	Total

*Material specified to quality assurance provisions of Section 4 MIL-A-8920A and mechanical property limits of Table II.



ALL DIMENSIONS IN INCHES

DIMENSION			
A	-	Width at center	.50 + .01 - .01
B	-	Width at grips	.75
C	-	Length of reduced section	2.40 min.
D	-	Grip length	2.90 min.
F	-	Fillet radius	.50 min.
G	-	Gage length	2.00 + or - 0.005
L	-	Total length	9.00

Reference:
Fed. Test Method Std. No. 151a, Method 211.1, Type F2

Figure 2. Finish Machined Tensile Test Coupon (Longitudinal and Transverse)

Table III. "As Received" Mechanical Properties 6Al-4V ELI Titanium Alloy

MECHANICAL / METALLURGICAL

QUALITY VERIFICATION TEST REQUEST/REPORT

SER. 24799

TYPE OF JOB: Mechanical Properties	DATE SUBMITTED: 7/8/68	CHEM ANALYSIS: [ ]	QVL NO. 8-5723
REQUESTER: R. Bruce		PLANT NO. 71	DEPT. NO. 403-30
TYPE OF MATERIAL: 6 Al-4 V Titanium	AWO: 720-3302-918	SPEC. NO. MIL-T-9046	MAN-HOURS: 3.0
REC. REP. 459783	P.O. 46-07004	P/N 68-59788-9	S/N
HEAT NO. G-4955	LOT	GAGE .040 x 36 x 96	COIL NO.

SAMPLE	DIMENSIONS: THICKNESS OR DIA.	WIDTH	AREA	MECHANICAL PROPERTIES: YIELD (2% OFFSET) LBS.	YIELD (2% OFFSET) KPSI	ULTIMATE LBS	ULTIMATE KPSI	ELONG. % IN 2" — 4D	HARDNESS	R OF A %	TEST TEMP.
TRAN											
1.	.0401	.9030	.0202	2650	131.2	2815	139.4	10.0			
2.	.0410	.5030	.0206	2750	133.5	2850	138.3	10.0			
3.	.0415	.5030	.0209	2825	135.2	2925	139.9	12.0			
LONG											
1.	.0390	.5055	.0197	2675	135.8	2765	140.4	12.0			
2.	.0390	.5060	.0197	2700	137.1	2785	141.4	12.0			
3.	.0389	.5062	.0197	2675	135.8	2765	140.4	10.0			

REMARKS: Data Only - Material Conforms to MIL-T-9046

SPEC. REQTS. Mil-T-9046 Minimums	120.0	130.0	8.0	
OPERATOR W.E. Nichols	MACHINE 50K T-O	DATE 7/11/68	CHECKED BY	P S Rader

The aluminum alloy quality verification test results, Table IV, compare favorably with the vendor certification results shown in Table II and are within the normal test result scatter. Heat treat response tests, Table V, were conducted on several material sheets to verify that the final condition of the material could meet program requirements. Heat treatment was performed to MIL-H-6088D except the solution heat treat temperature was 985° ±10°F for 1 hour and cold water quench as recommended by the supplier. The material was artificially aged at 325° ±10°F for 16 hours. The results indicate a 5 percent lower value on yield strength and 7.9 percent on ultimate strength from vendor typical data.(5)

Tensile testing done on subsequent specimens, shown in Section 3.9, Table XVIII, produced results of 2.6 percent lower values on yield strength and 4.1 percent lower values on ultimate strength from vendor typical data. The values, however, are within the material design allowables, F_{tu} 67,000 psi, F_{ty} 57,000 psi and 3 percent elongation minimum.

2.4.3 MATERIAL PROCESSING. The principal concern during the establishment of the processing sequence was certain operations which, if not properly controlled or sequenced, would adversely affect the mechanical properties, corrosion, and toughness characteristic of the materials and ultimately reduce the intended long-term service life of the finished article. Of particular concern were the X-2021 aluminum alloy fabrication process and metallurgical properties that could significantly affect the tank performance in the intended environment. These processes include solution heat treating temperatures and times, artificial aging, the effect of cold work on the properties of the material prior and subsequent to solution heat treatment, the final heat treat base material properties, weld joint properties, corrosion and stress corrosion resistance of the weld joint and weld joint allowables. The primary concern in the titanium tank processing involves the base material, oxygen, hydrogen, and cleaning solvent contamination during the intermediate anneal required in the hydroform process.

2.4.3.1 Titanium Alloy Processing. The titanium tankage material was processed in the annealed condition. All forming operations, cylinder section roll forming and bulkhead hydroforming, was performed cold. Bulkhead fittings were machined in the annealed condition.

The bulkhead hydroforming required three intermediate anneal operations to prevent cracking during drawing. The intermediate annealing was accomplished at 1400°F for one hour then air cooled. The final anneal was acomplished in accordance with MIL-H-81200.

To prevent hydrogen and oxygen embrittlement during air cooling, the titanium alloy blanks were encapsulated or sandwiched with cold rolled steel, welded at the edges and evacuated prior to the forming and annealing. The titanium and steel was solvent cleaned prior to sandwiching to prevent potential contamination. Cleaning was accomplished with methyl-ethyl-ketone or acetone rather than the commonly used trichlorethylene since solvents containing chlorides can cause embrittlement.

Table IV. "As Received" Mechanical Properties X-2021-O Aluminum Alloy

24999

MECHANICAL / METALLURGICAL

QUALITY VERIFICATION TEST REQUEST/REPORT

SER.

TYPE OF JOB: Physical Properties
CHEM. ANALYSIS: [ ]
GVL NO.: 8-9201

REQUESTER: Fred Fujimoto KM x3597
DATE SUBMITTED: 11-8-68
PLANT NO.: 71
DEPT. NO.: 512-20

TYPE OF MATERIAL: 2021 Aluminum
AWO: 720-3302-918
SPEC. NO.: None
MAN-HOURS:

REC. REP.:
P.O.:
P/N: 68-59788-19
S/N: T712989

HEAT NO.:
LOT:
GAGE: .064
COIL NO.:

SAMPLE	DIMENSIONS: THICKNESS OR DIA	DIMENSIONS: WIDTH	DIMENSIONS: AREA	YIELD (.2% OFFSET) LBS	YIELD (.2% OFFSET) KPSI	ULTIMATE LBS.	ULTIMATE KPSI	ELONG. % IN 2" — 4D	HARDNESS	R OF A %	TEST TEMP.
Annealed											
1T	.0668	.4913	.0328	346	10.5	742.5	22.6	20.0			
2T	.0668	.4968	.0332	329	9.9	751.5	22.65	19.0			
3T	.0671	.4904	.0329	340	10.3	737.0	22.4	19.0			
1L	.0669	.4949	.0331	320	9.6	750.5	22.6	22.0			
2L	.0667	.4963	.0331	360	10.9	746.0	22.55	22.0			
3L	.0666	.4942	.0329	339	10.3	749.0	22.1	20.5			
T42											
T	.0667	.5028	.0335	733	21.9	1530.0	45.7	22.0			

REMARKS: Data Only

SPEC. REQTS.:

OPERATOR: W.M.Parker
MACHINE: 120,000 T/O
DATE: 12-18-68
CHECKED BY: F.J.Phillips

Table V. Quality Verification Test -- Heat Treat Response of X-2021 Aluminum Alloy

SAMPLE SHEET NO.	THICKNESS	WIDTH	AREA	YIELD (.2% OFFSET) LBS.	YIELD (.2% OFFSET) KSI	ULTIMATE LBS.	ULTIMATE KSI	ELONG. % IN 2"
IL	.0668	.5262	.0351	2250	64.1	2500	71.2	12
IL	.0668	.5262	.0351	2085	59.4	2375	67.7	10
IT	.0668	.5286	.0353	2120	60.0	2450	69.4	11
4	.0668	.5238	.0350	2150	61.4	2400	68.6	11
4	.0668	.5264	.0352	2180	61.9	2425	68.9	10
5	.0676	.5262	.0356	2185	61.4	2440	68.5	9
5	.0676	.5250	.0355	2190	61.7	2450	69.0	10
AVG					61.7		69.1	10.4
TYPICAL 2021-T62 PROPERTIES					65.0		75.0	8.0

NOTES: Solution heat treat temperature 985°F for one hour; water quench; age at 325°F for 16 hours, air cool.

The intermediate annealing operation was in variance with MIL-H-81200 requirements which specify the thermal cycle to be 1300°F to 1350°F for one hour, cooled at the rate of 50°F per hour until 800°F, then air cooled. The process was changed because of the time consuming (10 hours) cooling rate and cost, and because it was not required for forming. The 1400°F temperature cycle does not have significant adverse metallurgical effects such as effects on alpha-beta precipitates, embrittlement, etc. Yield strength is affected by approximately five percent. The final anneal operation was accomplished in accordance with MIL-H-81200 at 1325°F for one hour, thus resulting in no yield strength loss in the finished bulkheads. Deliverable tensile coupons were given the same thermal cycling and processing. Forming, however, was not accomplished on the tensile specimens.

2.4.3.2 Aluminum Alloy Processing. Table VI provides a summary of various processing sequences for X-2021 aluminum alloy evaluated for this program. Condition 1 represents the processing sequence for the fill and drain port. Condition 5 represents the processing sequence for the bulkheads and cylinder sections. Conditions 2, 3, 4, and 6 represent alternate bulkhead and cylinder processes considered and are discussed below.

The thermal treatments, annealing, stress relief, solution heat treat, and aging are specified in the general notes of Figure 1 and were derived from the suppliers' recommendations.[6,7]

Available data on stress corrosion cracking (SCC)[3] indicates that X-2021 aluminum alloy sheet material is susceptible to SCC in the solution treated plus weld condition and should not be used in the "as welded" condition. The post-weld solution heat treat and artificial age condition has a high SCC resistance; however, it is not a practical consideration for this tankage program. Substantial distortion can be expected in the solution heat treat process due to the high treat temperature (985°F) and the subsequent cold water quench. Cold water quenching of a completed tank was considered impractical.

Condition 1 of the Table VI, the solution heat treat plus weld plus age condition represents the maximum strength levels for processing the machined fitting. It possesses a reasonable SCC resistance in both the sheet and plate with a threshold stress of 37.7 ksi and 27.0 ksi respectively. The process was therefore selected for fabrication of the machined fittings based on the strength, fabrication and SCC standpoint.

Condition 2 of Table VI represents the maximum strength levels for processing of bulkheads and cylinders. Condition 3 is nearly identical to Condition 2 except for the stress relief and sizing operation. Both processes were rejected for the following reasons:

Table VI. Summary of Various Processing Sequences for X-2021 Aluminum Alloy

Condition	Annl.	Form	Stress Relief	Sol. Heat Treat	Pre-Age	Form	Size	Mach	Weld	Age	Final* Cond.	Typical Base Material Prop., Percent F_{tu}	Typical Base Material Prop., Percent F_{ty}
1	X			X				X	X	X	-T62	100	100
2	X	X		X					X	X	-T62	100	100
3	X	X	X	X			X		X	X	-T81	96	92
4	X	X	X	X	X		X		X	X	-T81	97	94
5	X			X		X			X	X	-T8X	95	91
6	X			X	X	X			X	X	-T8X	96	93

NOTES:

Condition 1 - Processing sequence of fill and drain ports
Condition 5 - Processing sequence of tank cylinder and bulkheads
Conditions
2,3,4 & 6 - Other processing sequences considered for tank bulkhead and cylinder

*Final Condition -T81 and -T8X Designation: Cold work introduced between quenching and artificial age, but does not identify user Sol. H.T. T62 Designation: Heat treated by user with no cold working between quenching and aging. Since cold work introduced during the roll forming and sizing is less than 1.5% cold work can be discounted. Final heat treatment obtained by the user more adequately describes the final condition of the base material. Tank final condition therefore will be called -T62.

a. Extensive and excessively large grain size can occur when a critical amount of cold work is introduced in the forming of the bulkheads and subsequently manifests itself during annealing or solution heat treat. This condition is undesirable from a welding and mechanical property standpoint. Once grain growth occurs the condition can not be alleviated in the finished part.

b. Excessive distortion and warpage during the solution heat treat cannot be tolerated in the subsequent EB welding process.

Condition 4 of Table VI is nearly identical to Condition 3 except for the pre-aging requirements of Condition 4. Pre-aging before sizing will increase strength levels subsequent to aging; however, the improvement in strength for the additional pre-age operation does not justify the small strength gain.

Conditions 5 and 6 are nearly identical except for the pre-aging prior to the forming sequence in Condition 6. The pre-aging before forming, as in Condition 4, results in small strength gain and does not warrant the additional heat treat operation. Condition 5 was the selected process for the fabrication of the cylinders and bulkheads. Roll forming of the cylinder after solution heat treat will remove the distortion and warpage during the solution heat treat process and will provide the close tolerances required for the subsequent EB welding operation. Hydroforming of the bulkhead in the solution heat treated condition also provides close tolerance required for the EB weld process. In addition, the potential grain growth problem inherent in the solution heat treat after forming is circumvented.

2.4.3.3 Aluminum Alloy Test Program. The intent of the test program was to determine 1) the feasibility of hydroforming in the solution heat treat condition and 2) to determine if grain growth will occur if the production bulkheads are formed in the annealed condition and subsequently solution heat treated. The test program was required since the hydroform vendor was reluctant to form the X-2021 aluminum alloy in the solution heat treated condition. His past experience with hydroforming other aluminum alloys has been to form in the annealed condition with subsequent heat treatment.

Recent Convair programs with aluminum alloys 2219 and 6061 indicated that a grain growth problem does exist when a substantial amount of cold work is introduced. This indicated that further precautions should be taken prior to committing bulkhead fabrication in the annealed condition. In order to least jeopardize the tankage program, in light of the limited quantity of material available, and reduce the risk to a minimum, four small test X-2021 aluminum alloy bulkheads were hydroformed. Two 12-inch diameter heads were formed using the annealed plus form plus SHT process and two 12-inch diameter heads were formed using the SHT plus form process. These bulkheads were hydroformed by the California Hydroform Company, the vendor selected to form the production bulkheads.

A full-size test bulkhead was not formed for two reasons: 1) unavailability of sufficient material, and 2) full-scale test bulkheads would incur additional costs to the program while the 12-inch bulkhead dies were already set up by the vendor.

Results of these test pieces reveal that grain growth will occur and present a problem (Figures 3, 4, 5, and 6). The test also indicated that the production bulkheads can be hydroformed in the solution heat treated and freshly quenched condition without major difficulties (Figures 3, 4, 7, and 8). Tests were made to determine if this recrystallized or large grain region had lower mechanical properties than the small grain region and to compare the tensile properties of the two bulkheads in both the as-formed and as-formed plus aged conditions.

Figure 9 shows the locations of pie-shaped segments taken from each bulkhead. Figure 10 shows the distribution of Rockwell E hardness values. There is no apparent change in hardness across the large grain region. Micrometer readings were also taken adjacent to each hardness impression. The thinnest sections do not correspond to the large grain region. Tensile blanks were sawed from the center and side of each bulkhead. One radial section was taken from the bulkhead formed after annealing which included a large grain region. The results of the hardness and tensile tests on these specimens are listed in Table VII. The tensile specimen with a large grain region failed through a region of 0.035-inch grain diameter.

Based on a limited number of tests, the sequence of forming and heat treating operations has negligible effect on the tensile properties of 2021-T81 aluminum. The presence of large grains (up to 0.125 inch in diameter) did not affect the tensile strength, but reduced the percent elongation and reduction in area by approximately 50 percent. There is an apparent linear relationship between Rockwell E hardness and ultimate tensile strength for the range of tensile strength investigated (Figure 11).

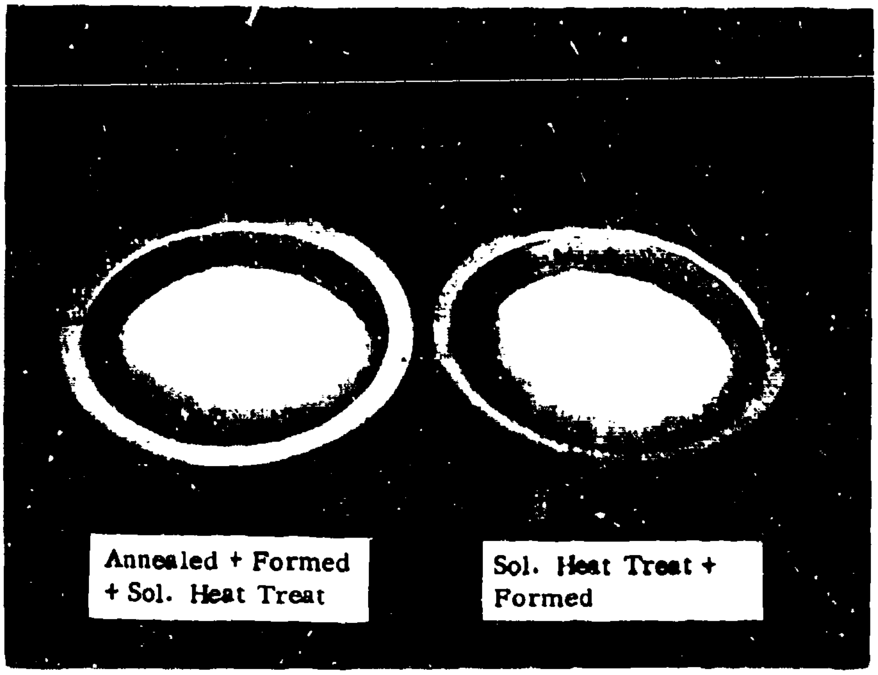


Figure 3. Test Hydroformed 12-Inch-Diameter Bulkhead (Inside View)

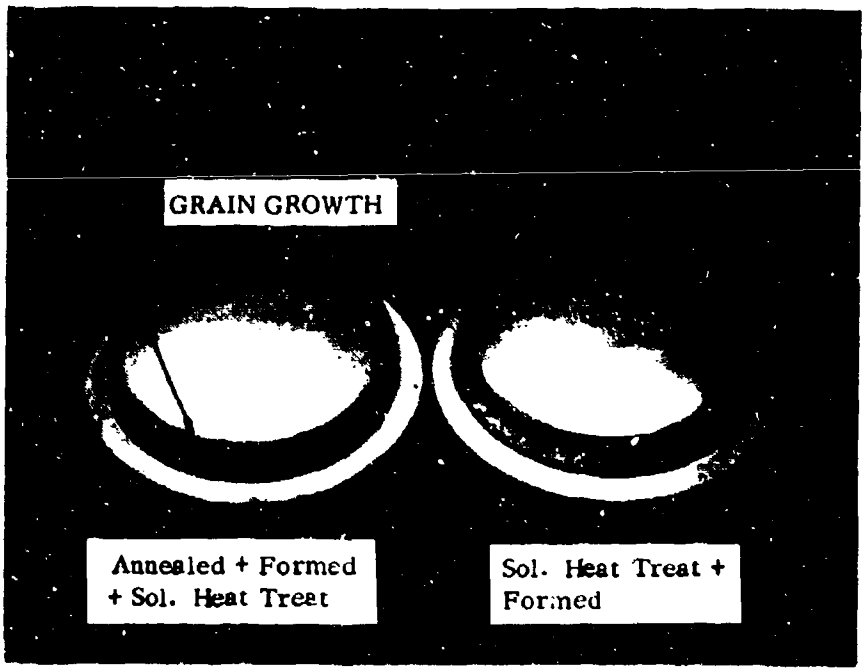


Figure 4. Test Hydroformed 12-Inch-Diameter Bulkhead (Outside View)

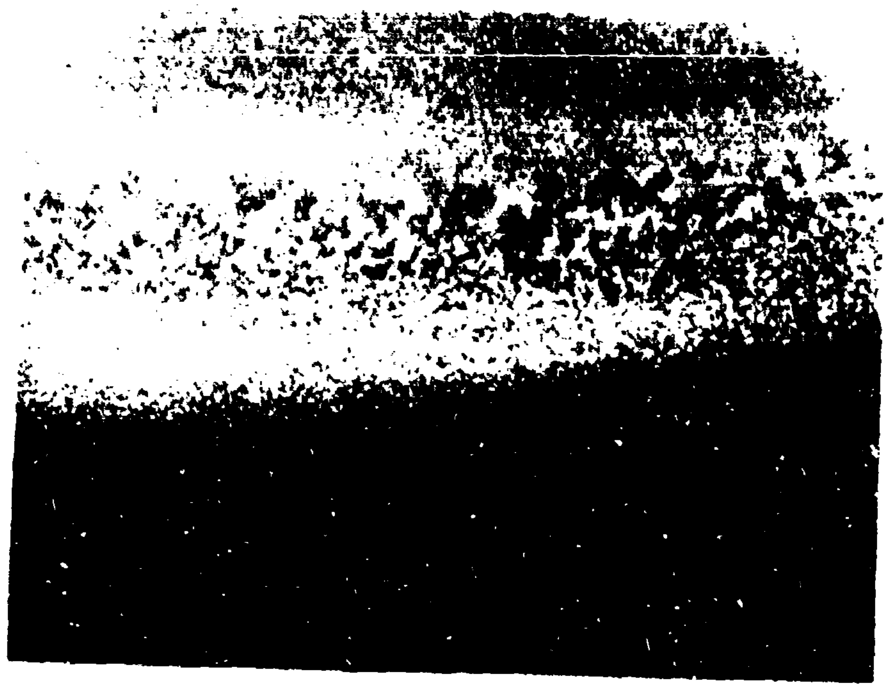


Figure 5. Grain Growth of Annealed Plus Form Plus Solution Heat Treated Bulkhead

Figure 6. Grain Growth of Annealed Plus Form Plus Solution Heat Treated Bulkhead

Figure 7. Solution Heat Treated Plus Formed Bulkhead

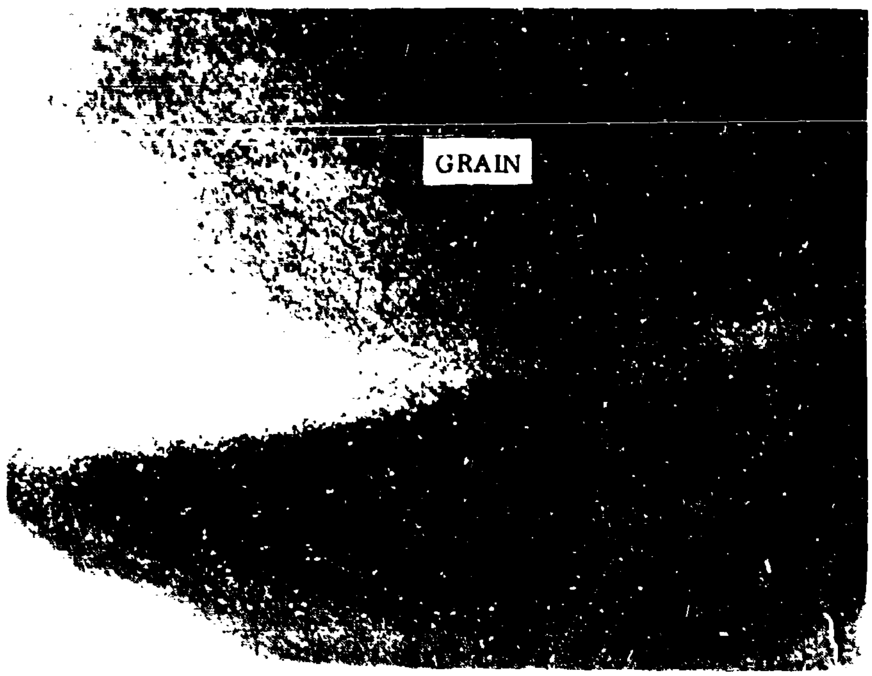


Figure 8. Solution Heat Treated Plus Formed Bulkhead

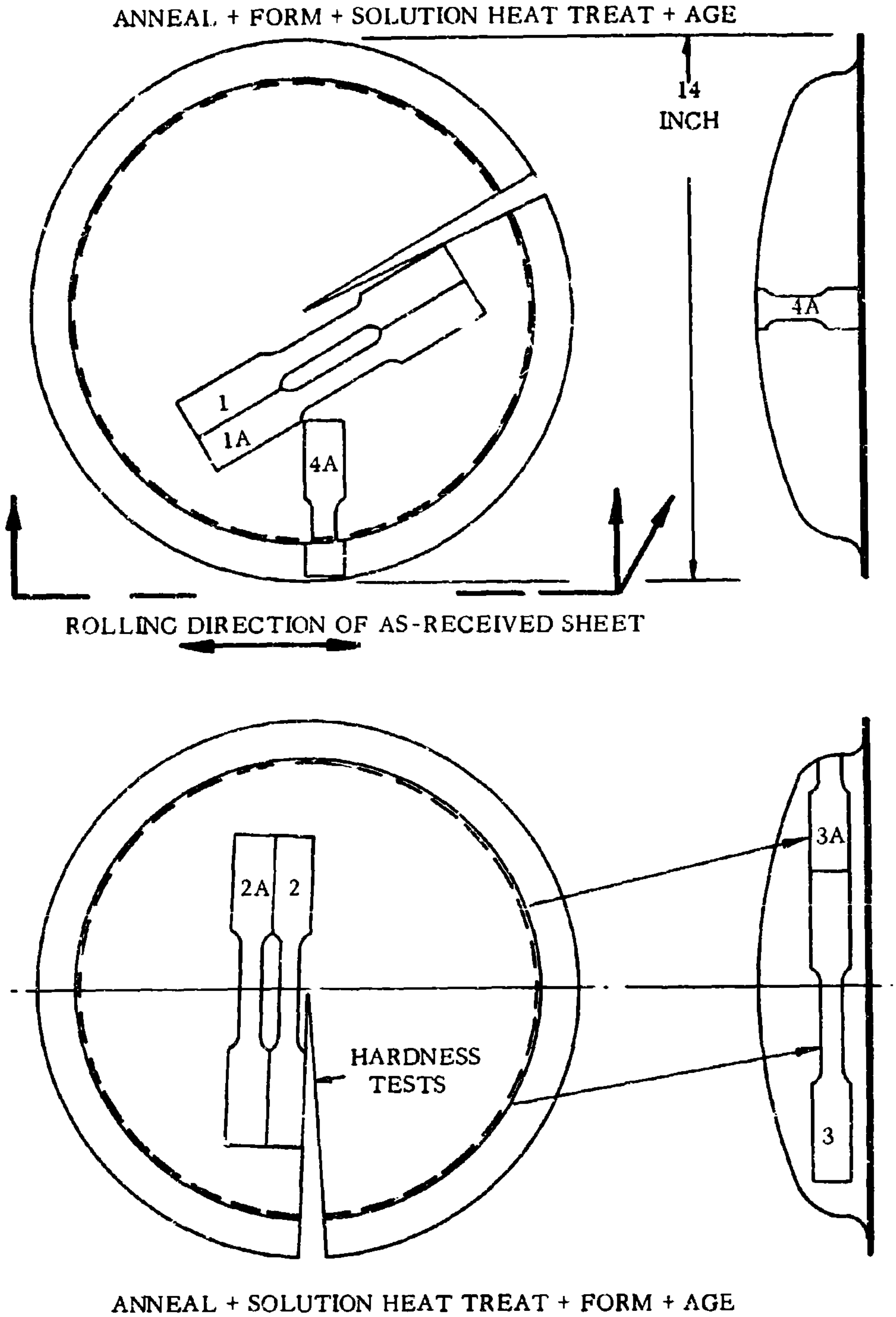


Figure 9. Location of Samples from Test 2021 Aluminum-Alloy Bulkheads

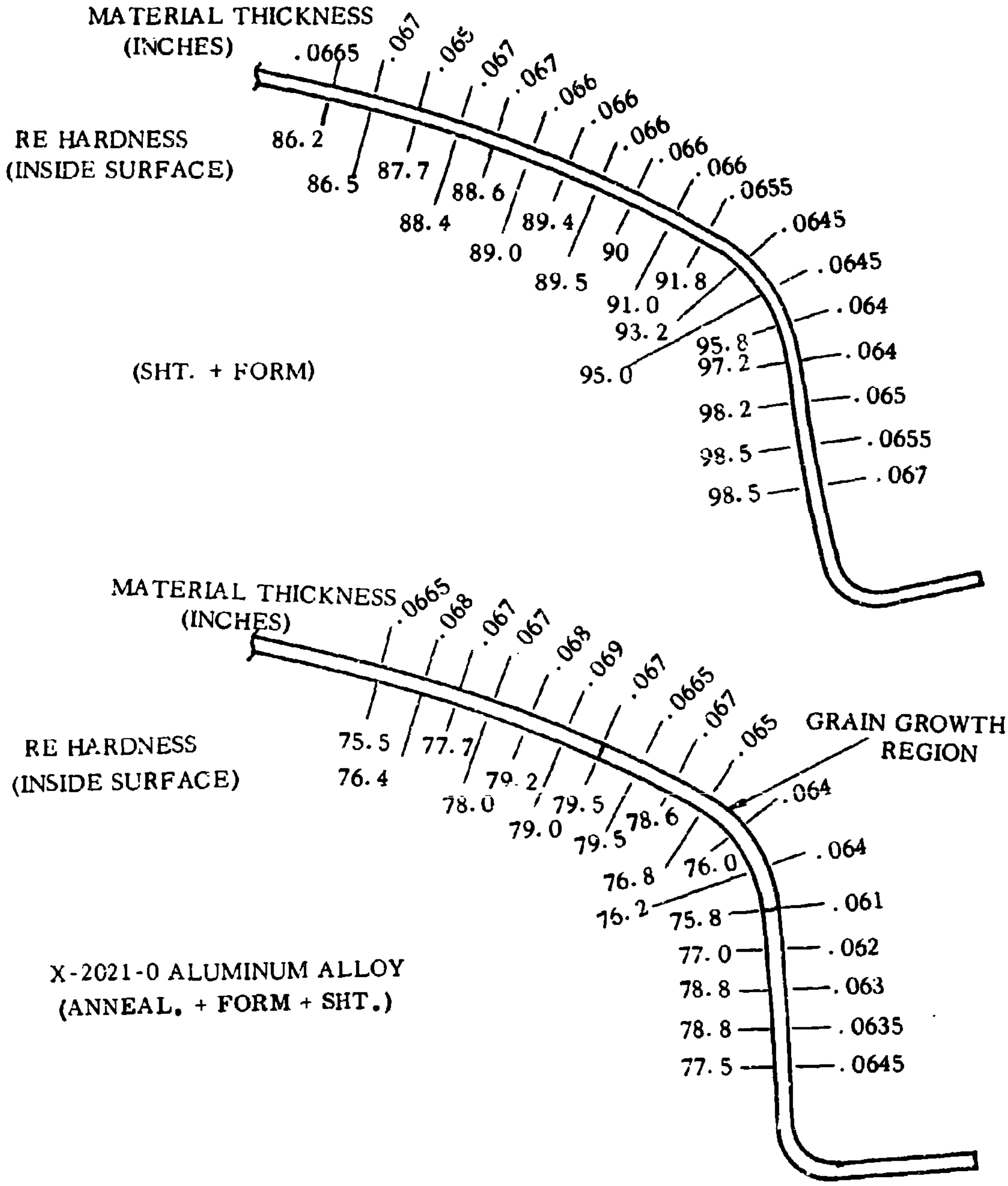


Figure 10. Test Bulkhead Hardness Readings

Table VII. Tensile Data from Selected Sections

Bulkhead	Specimen No. and Location of Test Section No.	Location	F_{ty} KSI	F_{tu} KSI	% Elongation of 2"	% Reduction in Area	Rockwell E Hardness(100kg)
Anneal Form Solution treat	1	Center	21.1	47.6	24.0	54.5	79.0
Solution treat Form	2	Center	27.9	51.7	20.5	54.0	87.5
Solution treat Form	3	Side	47.7	60.2	9.5	57.0	99.0
Anneal Form Solution treat Age	1A	Center	66.8	72.5	8.0	22.0	105.5
Anneal Form Solution treat Age	4A	Radial section including large grain area	60.8	69.6	4.0	10.1	105.1
Solution treat Form Age	2A	Center	62.5	72.9	8.5	19.6	105.5
Solution treat Form Age	3A	Side	54.9	67.2	8.5	27.2	102.2

NOTE: Figure 11 correlates the above ultimate tensile strength with the corresponding Rockwell E readings.

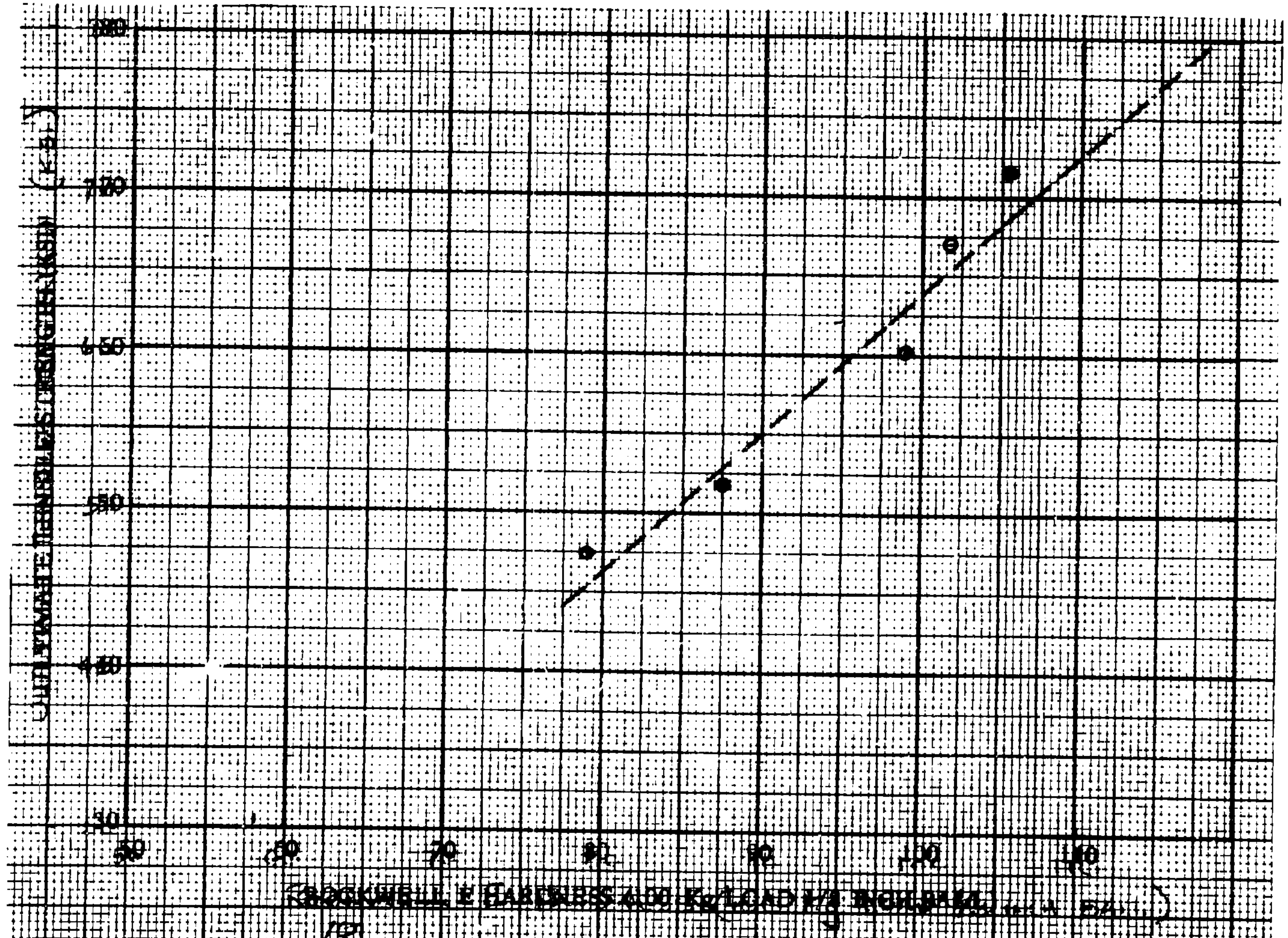


Figure 11. 0.064-Inch-Thick 2021 Aluminum-Alloy Rockwell E Hardness vs. Ultimate Tensile Strength

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SECTION III

TANK FABRICATION

Twelve tanks were fabricated, six from the 6Al-4V titanium alloy and six from the X-2021 aluminum alloy, having similar geometry and a capacity of approximately 15 gallons. Each tank has a constant section main shell, 18 inches in diameter and 5.4 inches in length, and is enclosed by ellipsoidal bulkheads. The bulkheads were fabricated by a one-piece deep draw hydropress form technique by Cal-Hydroform Company, El Monte, California. Each bulkhead apex was fitted with a fill or drain port. Close tolerance machining and fitting of parts were maintained to obtain weld quality of the tank joints. The tank detail manufacturing and assembly sequence followed is shown in Figure 12.

Seven special tools were fabricated for the compete tank fabrication and test. These tools were:

a. Tooling Fixture 68-59788-7 AU-17 TUFX. This fixture was used to finish trim the bulkhead-cylinder mating interface and to bore the 2.50- and 3.00-inch-diameter hole in the bulkhead apex for the fill or drain fitting.

b. Bulkhead Weld Fixture 68-59788-13 and -23 WLFX. This fixture, Figure 13, was used to locate the fill or drain fitting within the bulkhead hole for electron beam (EB) welding. The bulkhead is fitted over the 18-inch-diameter circular plate. The center post, with a copper backup ring, nests under the bulkhead hole. The bulkhead is clamped to the center post by the annular ring with three legs to the bottom of the 18-inch-diameter circular plate. The threaded stud, attached to the center post, positions and clamps the bulkhead fitting to the center post copper backup ring.

c. Cylinder Weld Fixture 68-59788-9 AU-19 WLFX. This fixture, Figure 14, was used to butt-fit the tank cylinder for longitudinal straight line welding. The fixture consists of an inverted "U" frame, with a 9-inch-radius saddle, upon which the cylinder is clamped for welding.

d. Trim Fixture 68-59788-9 AU-19 Production Aid "Pi". This fixture consisting of two 18-inch-diameter circular plates, spaced 5.40 inches apart, was used to trim the cylinders to net width.

e. Tank Assembly Weld Fixture 68-59788-1 AU-3 WLFX. The tank assembly weld fixture, Figure 15, consists of four separate pieces. They are: two one-inch-wide, 18-inch-diameter circular clamps, with holes spaced on one-inch centers around the circumference of the clamp, and two threaded adapters. The clamps are used to align the cylinder to bulkhead subassembly for tank welding. The threaded adapters are screwed onto the tank bulkhead fill and drain fittings and allow the tank assembly to be chucked to the horizontal turning fixture in the EB welder.

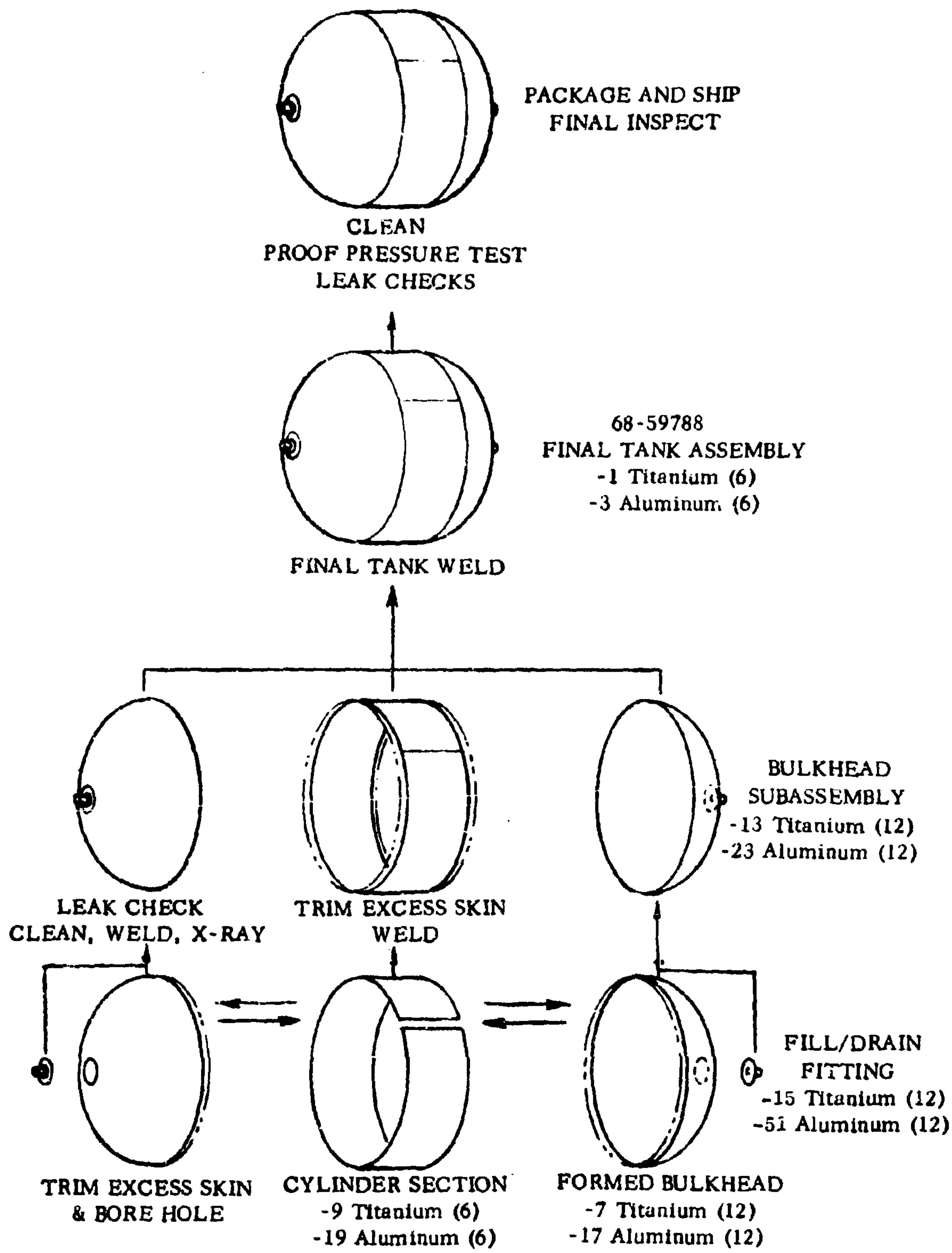


Figure 12. Manufacturing and Test Sequence and Flow

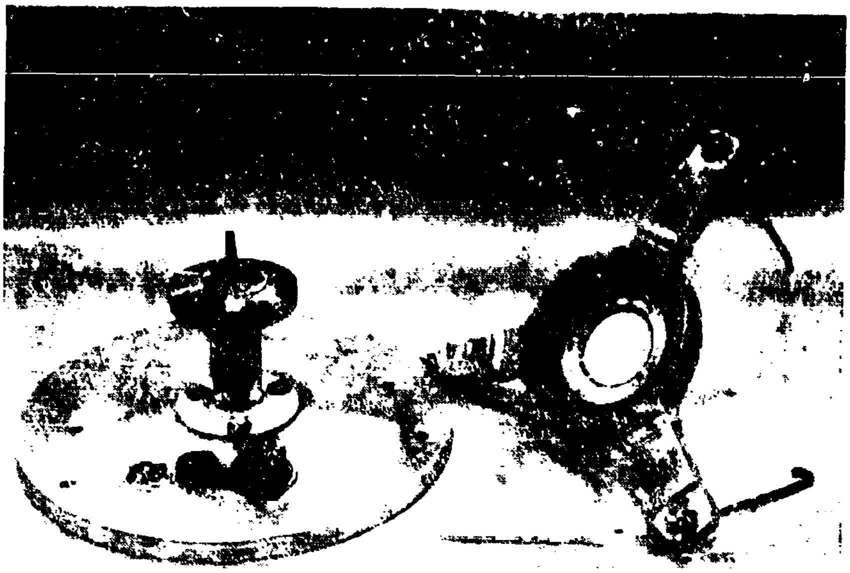


Figure 13. Fill or Drain Fitting Weld Fixture

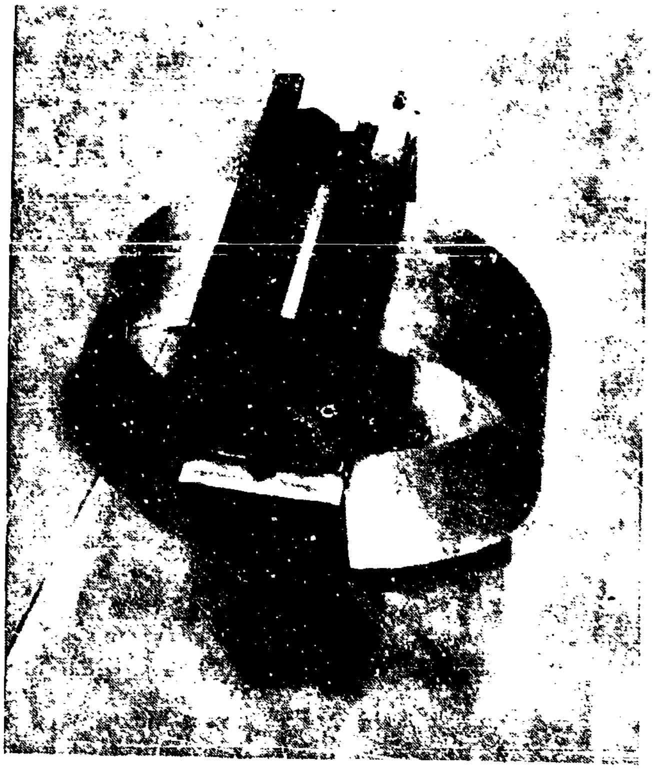


Figure 14. Cylinder Longitudinal Buttweld Fixture

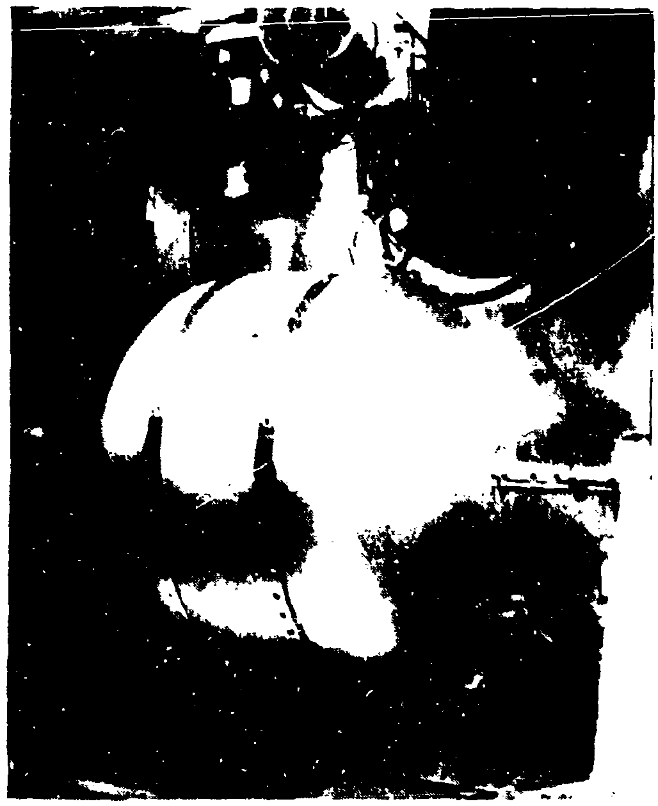


Figure 15. Final Assembly Tank Weld Fixture

f. Tube Subassembly Weld Fixture 68-59788-43 AU-45 WLFX. The tube subassembly weld fixture is a tool used to clamp and align the "MS" plain flange weld joint to the flared tube detail and allows clamping in the horizontal turning fixture.

g. Leak Check Test Tool 68-59788-13 AU-23 TSTO (Figure 16). The test tool consists of a circular plate beveled around the edge and grooved for a neoprene "O" ring gasket. The circular plate when placed inside the bulkhead provides a cavity between the circular plate and bulkhead fitting. The cavity can then be evacuated to determine weld integrity.

3.1 TANK PROCESSING

The processing flow charts for the six titanium and six aluminum-alloy tanks, from material receiving to their final delivery to the AFRPL, are outlined in Tables VIII and IX. These flow charts highlight the processing sequence that was employed to control each step. Inspection and leak-check procedures were sequenced into each key step of tank fabrication to reduce weld rework to a minimum.

Figure 16. Bu'khead Subassembly Leak Check Test Tool

The titanium sheet stock, 0.040 by 36 by 96 inches (7), processed in the annealed condition, was used to fabricate the 6 cylinders (68-59788-9) and 12 bulkheads (68-59788-7). The aluminum-alloy sheet stock, 0.064 by 36 by 96 inches (9), processed in the solution heat treated condition, was used to fabricate the 6 cylinders (68-59788-19) and 12 bulkheads (68-59788-17). The material was checked for dimensional tolerance, damage, accountability, and mechanical properties. Six tensile specimens of each material, three longitudinal and three transverse to the grain, were tested for "as received" mechanical properties (see Section 2.4.2). The results were compared with the suppliers acceptance certification test data and the military specification for conformance. The data results compare favorably. Each sheet of material was identified prior to detail cutting. The material was straight sheared, Lodge and Shipley eight-foot shear, then trimmed to the desired dimensions (Figure 17). Deliverable tensile coupons were sheared to a 12.0- by 13.5-inch rough size for processing along with the cylinders and bulkheads. All usable scrap material clippings were identified and stored for use during weld certification.

The bar stock material, purchased for the titanium tank fittings (68-59788-15), was ultrasonic-inspection tested, then shipped to the subcontractor for fitting fabrication. The X-2021 aluminum-alloy plate was cut to a 1.00- by 24- by 36-inch piece, solution heat treated, then processed for machining of tank fittings (68-59788-25).

Table VIII. Titanium Tank Processing Flow Chart

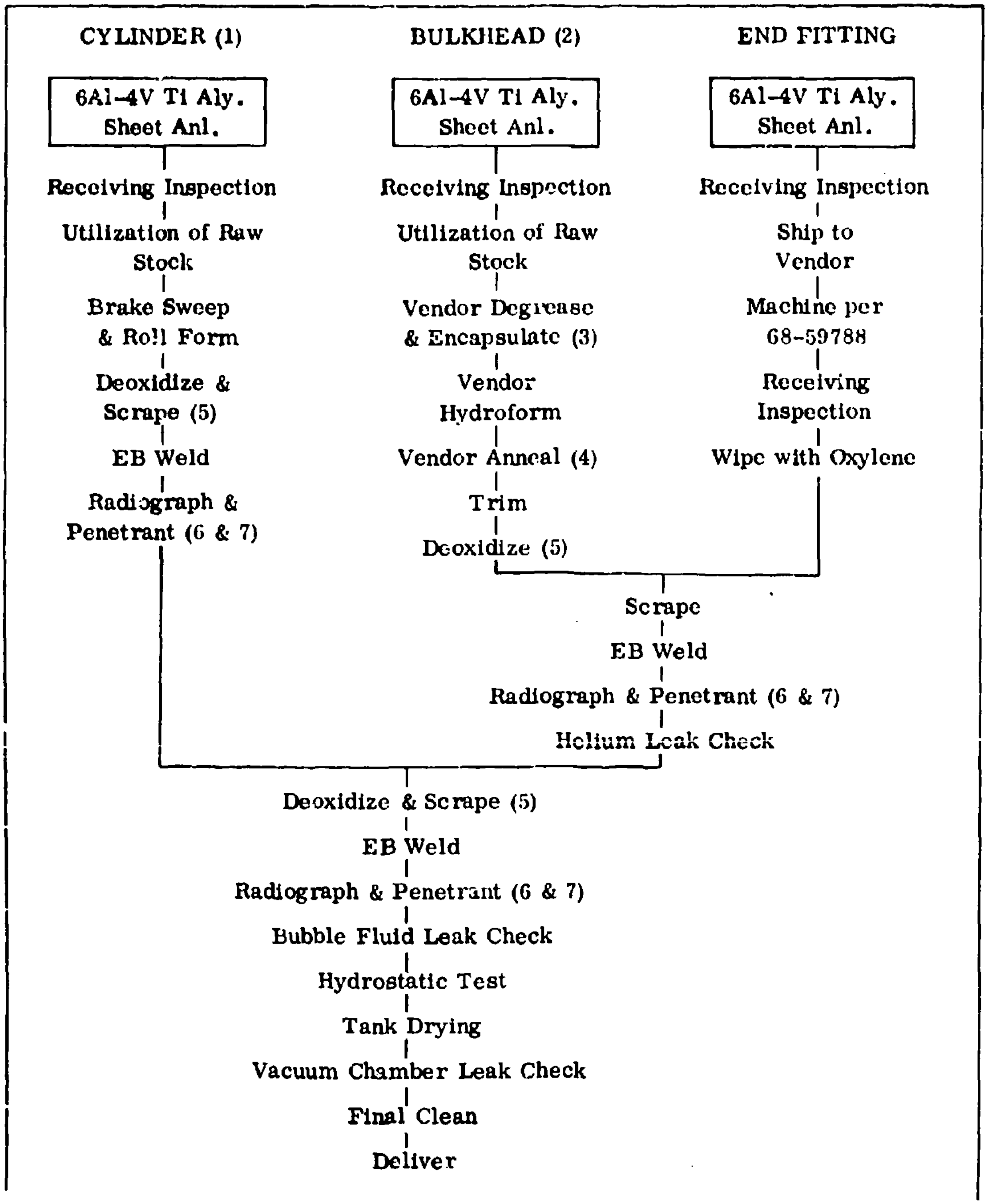


Table VIII. Titanium Tank Processing Flow Chart, Contd

TITANIUM NOTES:

1. Deliverable tensile coupons from the cylinder sheet to follow identical processing as cylinder section except for roll forming.

2. Deliverable tensile coupons from bulkhead blank sheet to follow identical processing as bulkhead except for vendor hydroforming operation.

3. Alkaline clean in Oakite 90, steel encapsulation material cleaned by a solvent wipe with methyl ethyl ketone (MEK).

4. Vendor hydroforming required 3 intermediate anneal. Annealing per MIL-H-81200, except anneal temperature was 1400°F for 1 hour, air cooled; final anneal per military specification.

5. Deoxidize with Oakite 90 and acid pickle with nitric acid and hydrofluoric acid.

6. Radiographic inspection per MIL-STD-453 (GD/C 0-75115) to acceptance standard of NAS1514 Class II.

7. Penetrant inspection per MIL-I-6866 Type B or C. No cracks are acceptable.

Table IX. Aluminum Tank Processing Flow Chart

CYLINDER (1)

- X2021-O Sheet
- Receiving Inspection
- Utilization of Raw Stock
- Vapor Degrease (3)
- Solution H. T. (4)
- Brake Sweep & Roll Form
- Deoxidize & Scrape (5)
- EB Weld 2319 Filler
- 100% Radiograph & Penetrant Inspect (6 & 7)

BULKHEADS (2)

- X2021-O Sheet
- Receiving Inspection
- Utilization of Raw Stock
- Vapor Degrease (3)
- Solution H.T. (4)
- Vendor Hydroform Trim
- Deoxidize (5)

END FITTING

- X2021-O Plate
- Receiving Inspection
- Utilization of Raw Stock
- Solution Heat Treat (4)
- Machine Per 68-59788
- Deoxidize (5)

BULKHEADS and END FITTING (joined)

- EB Weld - 2319 Filler
- 100% Radiograph & Penetrant Inspect (6 & 7)
- Helium Leak Check

CYLINDER and BULKHEAD assembly (joined)

- Deoxidize & Scrape (5)
- EB Weld - 2319 Filler
- 100% Radiograph & Penetrant New Welds (6 & 7)
- Bubble Fluid Leak Check
- Artificial Age (8)
- Hydrostatic Test
- Tank Drying
- Vacuum Chamber Leak Check
- Final Clean
- Deliver

Table IX. Aluminum Tank Processing Flow Chart, Contd

ALUMINUM NOTES:

1. Deliverable tensile coupons from the cylinder sheet to follow identical processing as cylinder except for roll forming.

2. Deliverable tensile coupons from the bulkhead blank sheet to follow identical processing as bulkheads except for vendor forming operation.

3. Degrease with trichorethylene, alkaline clean with Oakite 164, rinse and dry.

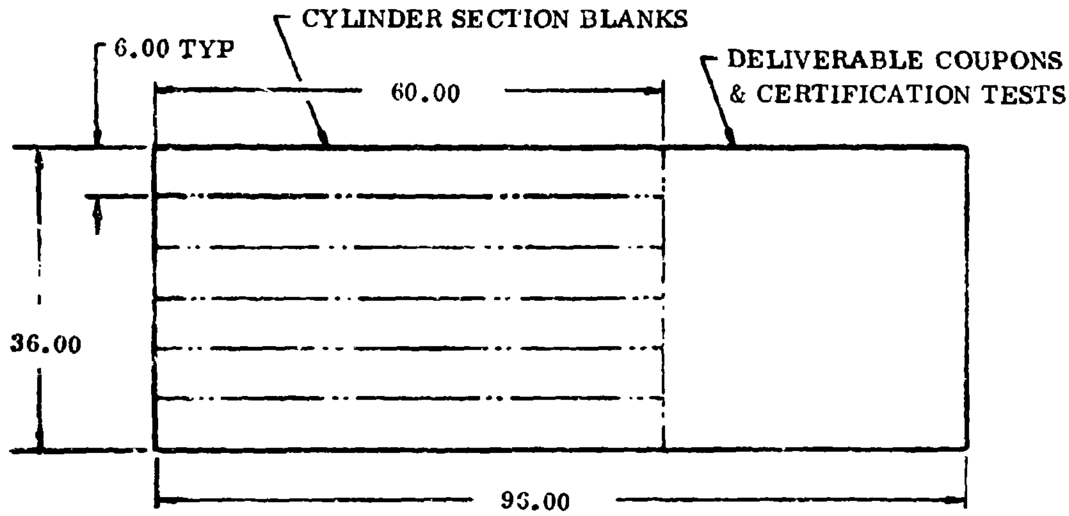
4. Solution heat treat per MIL-H-6088D except heat treating temperature 985° ±10°F for 1 to 1-1/4 hour, cold water quench, time to be 4 hours for plate stock.

5. Deoxidize with Wyandotte 2487 and chromic acid, water rinse and air dry.

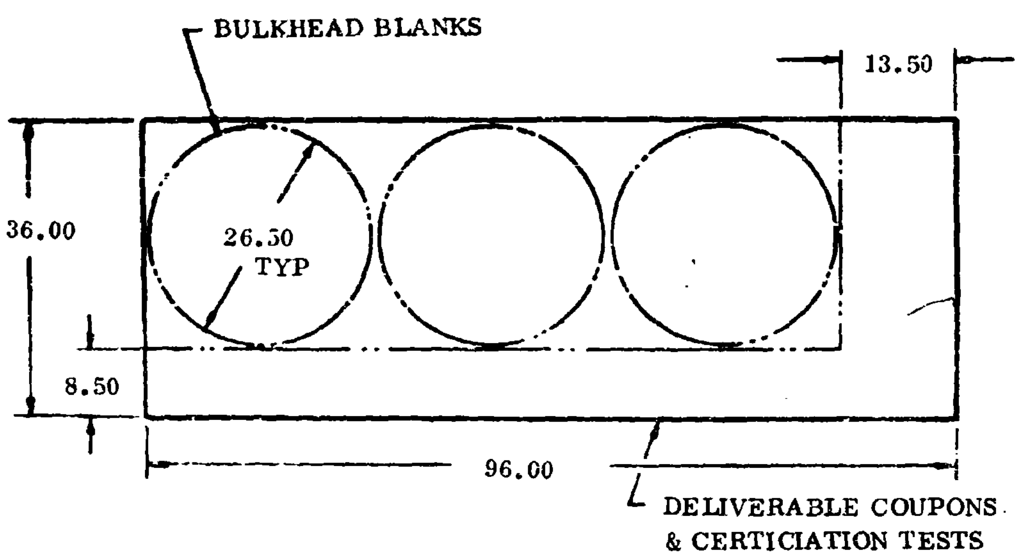
6. Radiographic inspection per MIL-STD 453 (GDC-0-75115) to acceptance standard of MIL-R-45774 Class II.

7. Penetrant inspection per MIL-I-6866 Type I. No cracks are acceptable.

8. Artificial age per MIL-H-6088D except age temperature to be 325° ±10°F for 16 to 16-1/4 hours.



TYPICAL SHEET MATERIAL UTILIZATION FOR ALUMINUM
AND TITANIUM ALLOYS - SHEET ONE ONLY



TYPICAL SHEET MATERIAL UTILIZATION FOR ALUMINUM
AND TITANIUM ALLOYS - SHEET TWO AND ON

Figure 17. Material Utilization

3.2 WELDING

The electron beam welding was accomplished on a Sciaky Electron Beam System, Figure 18, type VX-54K50X50, machine number 8564. Power output of the welder is 60 kV and 500 mA. Voltage supply is 460 volts, 60 cycle, three phase and 70 kVA. The welder is a complete unit with a vacuum chamber, pump, electron gun, and auxiliary equipment (accelerating voltage, filament current, and focus coil current). The chamber is equipped with an electric drive for positioning and feed mechanisms. The system is provided with an automatic seam tracker and automatic pumpdown system that prevents EB welding unless the desired vacuum (1×10^{-4}) is achieved. Alignment of the joint to be welded is accomplished by optical means, Figure 19. Vertical and horizontal alignment are provided by the electron gun. The lateral alignment is accomplished by the carriage, which carries the work piece.

3.2.1 <u>WELD SCHEDULES.</u> Seven different EB weld schedules were required for titanium and aluminum-alloy tank assembly. They are:

a. Titanium tank fitting to bulkhead (68-59788-15 to -7) and cylinder (68-59788-9) buttweld, Table X.

b. Titanium tank cylinder to bulkhead (68-59788-9 to -13), Table X.

c. 321 stainless steel tube subassembly (MS 27853-08 to 68-59788-49), Table XI.

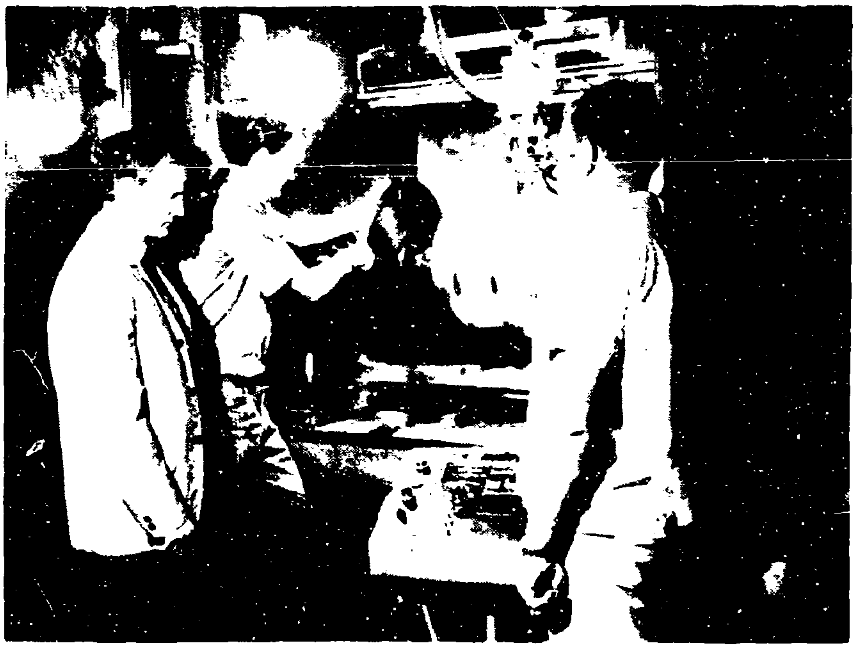


Figure 18. Electron Beam Welder

Figure 19. Electron Beam Welder Optical Alignment

d. 6061-T6 aluminum-alloy tube subassembly (MS 27858-08 to 68-59788-47), Table XI.

e. Aluminum-alloy cylinder (68-59788-19), Table XII.

f. Aluminum-alloy cylinder to bulkhead (68-59788-19 to -23), Table XII.

g. Aluminum-alloy tank fitting to bulkhead (68-59788-25 to -17), Table XII.

Weld schedule development requires establishment of weld parameters such as weld speed, accelerating voltage, focus coil current, weld wire feed rate, and gun-to-work distance. In addition, physical simulation of the production parts is required. These simulations include edge preparation, surface preparation and use of applicable production tools.

A typical simulated bulkhead to cylinder hoop weld is shown in Figure 20. Two cylinder sections 18.0 inches in diameter were processed in a similar manner as the production parts, then welded.

Table X. 6Al-4V Titanium Tank Weld Schedules

P/N 68-59788-1 PART NAME [illegible] Gallon Tank TYPE MATERIAL Titanium 6Al 4V

FIXTURE NO. Various ACCESSORY Flat Turntable MATERIAL THICKNESS .040

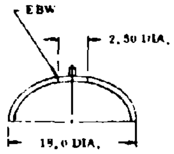
UPPER CONTROL PANEL

H.V. START DELAY OR TACKWELD: 010 SEC
MOTOR START DELAY: 000
H.V. START DELAY OR TACKWELD SWITCH 0-15-30-60-120
MOTOR START DELAY SWITCH 0-15-30-60-120

HIGH VOLTAGE INITIAL 21.0 KV FINAL 030 KV
INITIAL SLOPE RATE 0 SEC FINAL SLOPE RATE 180 (190) SEC

SPEED ADJUST INITIAL & FINAL NA IPM RUN NA IPM

TYPE JOINT Butt
MATERIAL COMBINATION
SKETCH OF JOINT



CENTER CONTROL PANEL

BEAM CURRENT 53 MA
HIGH VOLTAGE 21.0 KV
TRAVEL 50 IPM (Measure) X - Y - Z
BEAM CURRENT SWITCH POSITION OFF-X3-X2-X1
HIGH VOLTAGE SWITCH POSITION OFF-X2-X1
FOCUS CURRENT 3.3
GUN FILAMENT 65 AMPS
FILAMENT ADJUST 56

LOWER CONTROL PANEL

METER 10 RED POINTER 10 OPERATE READ
LOWER PANEL VACUUM GAGE METER 10

LOWER PANEL
VACUUM PUMPING SEQUENCE

VACUUM PUMPING SEQUENCE POWER ON
ROUGHING VALVE ON
POPPET VALVE ON
EVACUATE CHAMBER START

OPERATORS STATION CONTROLS

X-AXIS DRIVE SPEED ADJUST 30.0 IPM
BEAM ALIGN 050 AMP
FOCUS ADJUST 800 AMP
Y-AXIS DRIVE SPEED ADJUST 24.0 IPM
HIGH VOLTAGE ADJUST 21.0 KV

GUN ELEMENTS

COPPER SPACER YES NO
FILAMENT 250 MA
CATHODE 250 MA
ANODE 60 KV/MA
SPACER None
SPACING, CATHODE TO FILAMENT .364

PROJECTOR LENS
SPACER POSITION 1⅜ to 9 5/16, 3 3/8 to 18 1/16
GUN TO WORK DIST. 3.0 IN.

X-RAY SERIAL NO. 2X9029
ACCEPTANCE STD. 0-77008
METALLURGICAL EXAM --
APPROVAL W Roden WELDING ENGR.
APPROVAL W F Hageman PROCESS CONTROL

P/N 6d 59758 [illegible] PART NAME Cylinder 1 Bulkhead TYPE MATERIAL 6Al-4V Titanium annealed

FIXTURE NO. Tacking Band ACCESSORY Girth Lathe MATERIAL THICKNESS .040

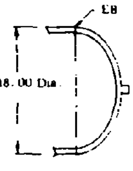
UPPER CONTROL PANEL

H.V. START DELAY: 00 SEC
MOTOR START DELAY: 0
H.V. START DELAY OR TACKWELD SWITCH 0-15-30-60-120
MOTOR START DELAY SWITCH 0-15-30-60-120

HIGH VOLTAGE INITIAL 18 KV FINAL 4 KV
INITIAL SLOPE RATE 0 SEC FINAL SLOPE RATE 150 SEC

SPEED ADJUST INITIAL & FINAL NA IPM RUN NA IPM

TYPE JOINT Sq. Butt
MATERIAL COMBINATION
SKETCH OF JOINT



NOTE: No heat sinks

CENTER CONTROL PANEL

BEAM CURRENT 35 MA
HIGH VOLTAGE 18.0 KV
TRAVEL 30 REF IPM X - Y - Z
BEAM CURRENT SWITCH POSITION OFF-X3-X2-X1
HIGH VOLTAGE SWITCH POSITION OFF-X2-X1
FOCUS CURRENT 5.1
GUN FILAMENT 42 AMPS
FILAMENT ADJUST 53

LOWER CONTROL PANEL

METER RED POINTER 10^{-4}
LOWER PANEL VACUUM GAGE METER 10

[illegible] NONE DIAMETER IN.
SIZE IN.
START DELAY
STOP DELAY
SPEED RATE

OPERATORS STATION CONTROLS

X-AXIS DRIVE SPEED ADJUST 10 REF IPM
BEAM ALIGN 050 MP
FOCUS ADJUST 715 AMP
Y-AXIS DRIVE SPEED ADJUST IPM
HIGH VOLTAGE ADJUST 17.0 KV

GUN ELEMENTS

COPPER SPACER YES NO
NEUTRAL FIELD YES NO X
FILAMENT 250 MA, TYPE Square
CATHODE 250 MA, TYPE Square
ANODE 60 KV/MA
SPACER None IN.
SPACING, CATHODE TO FILAMENT .363 IN.

PROJECTOR LENS
SPACER POSITION 1⅜ to 9 5/16, 3 3/8 to 18 1/16
GUN TO WORK DIST. 3.0 IN.

X-RAY SERIAL NO. 3X9031
ACCEPTANCE STD. NAS 1514 Class I
METALLURGICAL EXAM Satisfactory
APPROVAL s/s Roden WELDING ENGR.
APPROVAL s W F Hageman PROCESS CONTROL

Table XI. Tube Subassembly Weld Schedules

P/N 68-59788-45 PART NAME 15 Gallon Tank Tube & ?b Assy TYPE MATERIAL 321 CRES

FIXTURE NO. 68-59788-45 ACCESSORY Lathe with Gear Box MATERIAL THICKNESS .005

UPPER CONTROL PANEL

H.V. START DELAY OR TACKWELD: .010 SEC

MOTOR START DELAY: 0

H.V. START DELAY OR TACKWELD SWITCH 0-15-30-60-120

MOTOR START DELAY SWITCH 0-15-30-60-120

HIGH VOLTAGE INITIAL: 21 KV; FINAL: 050 KV

INITIAL SLOPE RATE: 0 SEC; FINAL SLOPE RATE: 150 SEC

SPEED ADJUST INITIAL & FINAL: NA IPM; RUN: NA IPM

CENTER CONTROL PANEL

BEAM CURRENT: 65 MA

HIGH VOLTAGE: 26.5 KV

TRAVEL: NA IPM

BEAM CURRENT SWITCH POSITION OFF-X3-X2-X1

HIGH VOLTAGE SWITCH POSITION OFF-X2-X1

X - Y - Z

FOCUS CURRENT: 3.7

GUN FILAMENT: 62 AMPS

FILAMENT ADJUST: 53

LOWER CONTROL PANEL

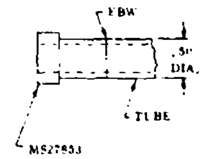
METER: 10^{-4}; RED POINTER: 10^{-4}; OPERATE READ:

LOWER PANEL VACUUM GAGE METER: [illegible]

TYPE JOINT Sq. Butt

MATERIAL COMBINATION

SKETCH OF JOINT



*Note: Use high speed [illegible] gear box.

LOWER PANEL

VACUUM PUMPING SEQUENCE

VACUUM PUMPING SEQUENCE POWER	ROUGHING VALVE	POPPET VALVE	EVACUATE CHAMBER
ON	ON	ON	START

GUN ELEMENTS

COPPER SPACER: YES NO

FILAMENT: 250 MA

CATHODE: 250 MA

ANODE: 60 KV/MA

SPACER: None

SPACING, CATHODE TO FILAMENT: .36

PROJECTOR LENS

SPACER POSITION 1½ to 9 5/16; 3 3/8 to 18 1/16

GUN TO WORK DIST.: 3.00 IN.

OPERATORS STATION CONTROLS

X-AXIS DRIVE SPEED ADJUST: NA IPM

BEAM ALIGN [illegible] AMP

FOCUS ADJUST: [illegible] AMP

Y-AXIS DRIVE SPEED ADJUST: [illegible] IPM

HIGH VOLTAGE ADJUST: [illegible] KV

X-RAY SERIAL NO. [illegible]

ACCEPTANCE STD. MIL-[illegible] Cl. II

METALLURGICAL EXAM

APPROVAL [illegible] WELDING ENGR

APPROVAL [illegible] PROCESS CONTROL

90-7-548

P/N 68-59788-43 PART NAME Tube - Sub Assy TYPE MATERIAL 6061-T6

FIXTURE NO. 68-59788-43 VLFX ACCESSORY High Speed Gearbox & Chuck MATERIAL THICKNESS .030

UPPER CONTROL PANEL

H.V. START DELAY OR TACKWELD: 000 SEC

MOTOR START DELAY: 000

H.V. START DELAY OR TACKWELD SWITCH 0-15-30-60-120

MOTOR START DELAY SWITCH 0-15-30-60-120

HIGH VOLTAGE INITIAL: 28 KV; FINAL: 022 KV

INITIAL SLOPE RATE: 0 SEC; FINAL SLOPE RATE: 60 SEC

SPEED ADJUST INITIAL & FINAL: Na IPM; RUN: NA IPM

CENTER CONTROL PANEL

BEAM CURRENT: 220 MA

HIGH VOLTAGE: 28 KV

TRAVEL: IPM

BEAM CURRENT SWITCH POSITION OFF-X3-X2-X1

HIGH VOLTAGE SWITCH POSITION OFF-X2-X1

X - Y - Z

FOCUS CURRENT: 4.6

GUN FILAMENT: 40 AMPS

FILAMENT ADJUST: 50

LOWER CONTROL PANEL

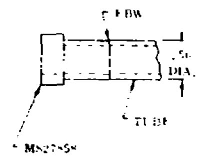
METER: 10^{-4}; RED POINTER: 10^{-4}; OPERATE READ:

LOWER PANEL VACUUM GAGE METER: mm.

TYPE JOINT Sq. Butt

MATERIAL COMBINATION

SKETCH OF JOINT



(VLFX tool not shown)

LOWER PANEL

VACUUM PUMPING SEQUENCE

VACUUM PUMPING SEQUENCE POWER	ROUGHING VALVE	POPPET VALVE	EVACUATE CHAMBER
ON	ON	ON	START

GUN ELEMENTS

COPPER SPACER: YES NO

FILAMENT: 250 MA

CATHODE: 250 MA

ANODE: 60 KV/MA

SPACER: .55

SPACING CATHODE TO FILAMENT: .365

PROJECTOR LENS

SPACER POSITION 1½ to 9 5/16; 3 3/8 to 18 1/16

GUN TO WORK DIST.: 3.00 IN.

OPERATORS STATION CONTROLS

X-AXIS DRIVE SPEED ADJUST: NA IPM

BEAM ALIGN: 050 AMP

FOCUS ADJUST: 680 AMP

Y-AXIS DRIVE SPEED ADJUST: 99.9 IPM

HIGH VOLTAGE ADJUST: 28.0 KV

X-RAY SERIAL NO. 2X9031

ACCEPTANCE STD. MIL-R-45774 Cl. II

METALLURGICAL EXAM

APPROVAL W. Eckert WELDING ENGR.

APPROVAL W. F. [illegible] PROCESS CONTROL

Table XII. X-2021 Aluminum-Alloy Tank Weld Schedule

P/N 68-59705-19 PART NAME CYLINDER TYPE MATERIAL 2021 ALUMINUM

FIXTURE NO. [illegible] ACCESSORY MATERIAL THICKNESS [illegible]

UPPER CONTROL PANEL

H.V. START DELAY [illegible] SEC — H.V. START DELAY OR TACK-WELD SWITCH 0-15-30-60-120

MOTOR START DELAY [illegible] — MOTOR START DELAY SWITCH 0-15-30-60-120

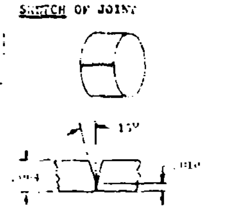
HIGH VOLTAGE INITIAL [illegible] KV FINAL [illegible] KV — INITIAL SLOPE RATE [illegible] SEC FINAL SLOPE RATE [illegible] SEC

SPEED ADJUST INITIAL & FINAL [illegible] IPM RUN — NA IPM

TYPE JOINT BUTT

MATERIAL COMBINATION [illegible]

SKETCH OF JOINT



NOTE: [illegible]

CENTER CONTROL PANEL

BEAM CURRENT [illegible] MA — LOW CURRENT SWITCH POSITION OFF-X3-X2-X1

HIGH VOLTAGE [illegible] KV — HIGH VOLTAGE SWITCH POSITION OFF-X2-X1

TRAVEL [illegible] IPM — X - Y - Z

FOCUS CURRENT [illegible] — GUN FILAMENT [illegible] AMPS — FILAMENT ADJUST 56

LOWER CONTROL PANEL

METER RED POINTER — LOWER PANEL VACUUM GAGE METER [illegible]

[illegible] [illegible] DIAMETER [illegible] IN.

SPEED [illegible] IPM — [illegible] 3

GUN ELEMENTS

COPPER SPACER YES NO — NEUTRAL FIELD YES NO — PROJECTOR LENS SPACER POSITION 1½ to 9 5/16, 3 3/8 to 18 1/16 — GUN TO WORK DIST. [illegible] IN.

FILAMENT [illegible] MA, TYPE [illegible]

CATHODE [illegible] MA, TYPE [illegible]

ANODE [illegible] KV/MA

SPACER NONE IN.

SPACING, CATHODE TO FILAMENT [illegible] IN.

[illegible] STATION CONTROLS

X-AXIS DRIVE SPEED ADJUST [illegible] IPM — BEAM ALIGN AMP NA — FOCUS ADJUST [illegible] AMP

Y-AXIS DRIVE SPEED ADJUST NA IPM — HIGH VOLTAGE ADJUST [illegible] KV

X-RAY SERIAL NO. [illegible]

ACCEPTANCE STD. MIL-R-45774 CL. II

METALLURGICAL EXAM [illegible]

APPROVAL [signature] WELDING ENGR.

APPROVAL [signature] PROCESS CONTROL

P/N 68-59768-9 to -11 PART NAME 15 Gal. Propellant Tank TYPE MATERIAL X2021

FIXTURE NO. Head & Tail Stock ACCESSORY 3 Jaw Chuck MATERIAL THICKNESS .066

UPPER CONTROL PANEL

H.V. START DELAY 0 SEC — H.V. START DELAY OR TACK-WELD SWITCH 0-15-30-60-120

MOTOR START DELAY 06.0 — MOTOR START DELAY SWITCH 0-15-30-60-120

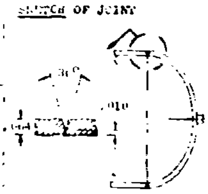
HIGH VOLTAGE INITIAL 22.5 KV FINAL 04.0 KV — INITIAL SLOPE RATE 10.0 SEC FINAL SLOPE RATE 199.0 SEC

SPEED ADJUST INITIAL & FINAL 3.4 ON POT IPM RUN — 5.5 ON POT IPM

TYPE JOINT Butt

MATERIAL COMBINATION X2021 - X2021

SKETCH OF JOINT



No Heat Sinks

*This weld made by automatic sequence

CENTER CONTROL PANEL

BEAM CURRENT 52.5 MA — LOW CURRENT SWITCH POSITION OFF-X3-X2-X1

HIGH VOLTAGE 22.0 KV — HIGH VOLTAGE SWITCH POSITION OFF-X2-X1

TRAVEL 40 IPM — X - (Y) - Z

FOCUS CURRENT 3.7 — GUN FILAMENT 55 AMPS — FILAMENT ADJUST 68

LOWER CONTROL PANEL

METER RED POINTER 10^{-4} 10^{-4} — LOWER PANEL VACUUM GAGE METER 10 MM

[illegible] 2319 DIAMETER .061 IN.

SPEED 110 IPM — START [illegible] 5.5 — [illegible] DELAY 0 — [illegible] 6

Scrape wire prior to weld

GUN ELEMENTS

COPPER SPACER YES X NO — NEUTRAL FIELD YES X NO — PROJECTOR LENS SPACER POSITION 1½ to 9 5/16, 3 3/8 to 18 1/16 — GUN TO WORK DIST. 2.95 IN.

FILAMENT 250 MA, TYPE Round

CATHODE 250 MA, TYPE Round

ANODE 60 KV

SPACER None IN.

SPACING, CATHODE TO FILAMENT .155 IN.

[illegible] STATION CONTROLS

X-AXIS DRIVE SPEED ADJUST NA IPM — BEAM ALIGN AMP NA — FOCUS ADJUST 0.40 AMP

Y-AXIS DRIVE SPEED ADJUST 40.0 IPM — HIGH VOLTAGE ADJUST 22.5 KV

X-RAY SERIAL NO. 5X-9046

ACCEPTANCE STD. MIL-R-45774 CL. II

METALLURGICAL EXAM Acceptable

APPROVAL WELDING ENGR.

APPROVAL PROCESS CONTROL

Table XII. X-2021 Aluminum-Alloy Tank Weld Schedule, Contd

P/N [illegible] PART NAME [illegible] TYPE MATERIAL [illegible]

FIXTURE NO. [illegible] ACCESSORY [illegible] MATERIAL THICKNESS [illegible]

E. B. CONTROL PANEL

H.V. START DELAY — [illegible] SEC — H.V. START DELAY OR TACKWELD SWITCH 0-15-30-60-120

MOTOR START DELAY — [illegible] — MOTOR START DELAY SWITCH 0-15-30-60-120

HIGH VOLTAGE INITIAL FINAL — [illegible] KV [illegible] KV — INITIAL FINAL SLOPE RATE SLOPE RATE — [illegible] SEC [illegible] SEC

SPEED ADJUST INITIAL & FINAL — NA IPM — NA IPM

TYPE JOINT [illegible]

MATERIAL COMBINATION [illegible]

SKETCH OF JOINT

CENTER CONTROL PANEL

BEAM CURRENT [illegible] MA

HIGH VOLTAGE [illegible] KV

TRAVEL [illegible] IPM

FOCUS CURRENT SWITCH POSITION OFF-X3-X2-X1

HIGH VOLTAGE SWITCH POSITION OFF-X2-X1

X - Y - Z

FOCUS CURRENT [illegible]

GUN FILAMENT [illegible] AMPS

FILAMENT ADJUST [illegible]

LOWER PANEL

METER READ POINTER

LOWER PANEL VACUUM GAUGE

BEHIND — FITTING

CHANGER [illegible] IN.

TENSILE [illegible] — [illegible] KSI

GUN ELEMENTS

CONTROL SPACER — YES NO

NEUTRAL [illegible] — YES NO

FILAMENT [illegible] MA, TYPE [illegible]

CATHODE [illegible] MA, TYPE [illegible]

ANODE [illegible] KV/MA

SPACER [illegible] IN.

SPACING, CATHODE TO FILAMENT [illegible] IN.

PROJECTOR LENS

SPACER POSITION 1½ to 9 5/16 — 3 3/8 to 14 1/16

GUN TO WORK DIST. [illegible] IN.

[illegible] STATION CONTROLS

X-AXIS [illegible] SPEED ADJUST NA IPM

BEAM [illegible] AMP ADJUST [illegible] AMP

Y-AXIS [illegible] SPEED ADJUST [illegible] IPM

HIGH VOLTAGE ADJUST [illegible] KV

X-RAY SERIAL NO.

ACCEPTANCE STD. [illegible]

METALLURGICAL EXAM [illegible]

APPROVAL [illegible] WELDING ENGR.

APPROVAL [illegible] PROCESS CONTROL

Figure 20. Typical Weld Schedule Test Specimen

For the schedules developed, filler wire was required only on the aluminum-alloy tank. The weld wire was 2319 aluminum alloy. A weld-wire-to-feed ratio of 3:1 with minimum weld wire dilution was required. A 30-degree V-groove was required to maximize the amount of filler used with minimum heat input into the parent material. The material supplier has recommended, at a minimum, one "t" gap to satisfactorily weld X-2021. However this process would not work with EB welding since the beam must be focused on the material to be welded.

Weld schedule certification was determined by visual, penetrant, and radiographic inspection for quality, and tensile testing for strength. X-ray requirements for the aluminum-alloy welds were MIL-R-45774, Class II, and for the titanium-alloy welds, NAS1514, Class II. The tensile strength was determined on the basis of two or more full section specimens cut from the test coupon, Tables XIII and XIV. For certification, the minimum tensile strength requirements were:

a. Aluminum alloy - 46,000 psi.

b. 6Al-4V titanium alloy - 123,500 psi.

The aluminum-alloy tensile specimens were aged at 325°F for one hour and air cooled prior to tensile testing. The titanium-alloy specimens were tested in the "as welded" condition. The tank close-out hoop weld test specimens on both the aluminum and titanium alloys were tack welded prior to the final weld to simulate as close as possible the actual bulkhead-to-cylinder close-out hoop weld.

3.2.2 WELD SCHEDULE DEVELOPMENT. Prior to establishment of schedules discussed in Section 3.2.1, weld schedule were developed using a typical 2219 EB weld schedule. The test panels simulating the cylinder longitudinal weld and bulkhead fitting welds were prepared using a square butt joint with a minimum gap. The test panels were welded using minimum 2319 filler wire. The welds were dye penetrant and X-ray checked for quality and tested for weld strength. Table XV presents the results of the tensile tests. The schedule and welds appeared satisfactory except the weld strengths were not as high as anticipated, but were higher than the tank design allowables of 40,300 psi. The weld schedule was accepted and production tank welding of the bulkhead fitting and cylinder longitudinal welds was accomplished using normal good aerospace welding practices. The weld joints were draw filed a minimum of one "t" to eliminate shear cracks from the trimming operation. The material was cleaned and scraped prior to welding. The weld fixture provided adequate clampdown and fixturing.

Upon inspection of the X-ray data, fine scattered porosity or microporosity was found on the fitting close-out weld, and large individual and linear porosity was found on the cylinder longitudinal welds. The discrepant areas were routed or ground out and repair welding using manual TIG with 2319 filler wire. Re-X-ray of the repair welds indicated some cracks and substantial scattered or microporosity, substantially worse than the original welds. Figure 21 depicts a typical fitting. It became apparent that

Table XIII. Titanium Tank Quality Verification Test

Sample	Thickness (inch)	Width (inch)	Area (in.^{2})	Ultimate (lb)	Ultimate (ksi)	Remarks
6Al-4V titanium alloy annl. (as welded) tank close-out hoop weld.						
1	0.0425	0.5090	0.0213	2775	130.3	No filler wire, failure P/M
2	0.0425	0.6499	0.0212	2785	131.4	No filler wire, failure P/M
3	0.0435	0.5010	0.0218	2785	127.8	No filler wire, failure P/M
Average					129.8	
Cylinder longitudinal butt weld and fitting weld.						
1	0.0415	0.2999	0.01245	1735	139.3	No filler wire, failure P/M
2	0.0420	0.2995	0.01258	1750	139.1	No filler wire, failure P/M
3	0.0420	0.2984	0.01253	1735	138.5	No filler wire, failure P/M
4	0.0420	0.2982	0.01252	1740	139.0	No filler wire, failure P/M
5	0.0420	0.2990	0.01256	1750	139.3	No filler wire, failure P/M
Average					139.0	
6Al-4V annealed plus weld design allowable 117.0.						

NOTE: (1) Full-section tensile specimen.

Table XIV. X-2021 Aluminum Alloy Quality Verification Tests

Sample	Thickness (inch)	Width (inch)	Area (in.^{2})	Ultimate (lb)	Ultimate (ksi)	Remarks
Bulkhead fitting weld.						
1	0.066	0.465	0.03069	1555	50.5	Failure heat affected zone
2	0.066	0.388	0.025608	1326	51.5	Failure heat affected zone
Average					51.0	
Longitudinal cylinder weld.						
1	0.0618	0.5025	0.0311	1245	40.0	Weld bead ground flush
2	0.0630	0.5051	0.0318	1250	39.3	Weld bead ground flush
3	0.0620	0.5010	0.0311	1227	39.5	Weld bead ground flush
Average					39.6	
1	0.0658	0.5000	0.0329	1765	53.6	Failure in heat affected zone
2	0.0660	0.4998	0.0330	1735	52.6	Failure in heat affected zone
Average					53.1	
Tank closeout hoop welds.						
1	0.0677	0.4962	0.03358	1810	53.9	Typical hoop weld, failure in heat affected zone
2	0.0672	0.4920	0.03306	1530	46.3	Overlap closeout, failure in heat affected zone
3	0.0669	0.4992	0.03339	1580	49.2	Intersection of hoop & long. butt-weld, failure in heat affected zone
Average					49.2	
X-2021 tank design allowable.					40.3	

NOTES: (1) Solution heat treat, weld plus age, 2319 filler wire.
(2) Solution heat treat per MIL-H-6088D except heat treat temperature was 985° ±10°F for 1 hour, cold water quench; age temperature 325°F for 16 hours, air cool.
(3) Unless otherwise noted specimens were full section.

Table XV. Square Butt-Joint EB Weld X-2021 Aluminum Alloy Tensile Test

Specimen No.	Thickness (inch)	Width (inch)	Area (in.^{2})	Yield (0.2% Offset) (lb)	Yield (0.2% Offset) (ksi)	Ultimate (lb)	Ultimate (ksi)	Elongation (% in 1 inch)
Solution heat treat plus weld.								
1	0.0651	0.4954	0.0322	-	-	1228	38.1	-
2	0.0652	0.4950	0.0322	-	-	1215	37.7	-
3	0.0654	0.4941	0.0323	-	-	1225	37.9	-
Average							37.9	
Solution heat treat - weld plus age (weld bead ground flush).								
1	0.0658	0.4956	0.0326	1195	36.6	1462	44.8	3.5
2	0.0658	0.4947	0.0326	1175	36.1	1405	43.2	3
3	0.0659	0.4947	0.0326	1135	34.8	1430	43.9	3
Average					35.8		44.0	3.2
Solution heat treat - weld plus age.								
1	0.0670	0.5010	0.6336	-	-	1725	51.3	-
2	0.0670	0.4980	0.0334	-	-	1725	51.6	-
3	0.0670	0.5030	0.0337	-	-	1700	50.4	-
4	0.0670	0.5070	0.0340	-	-	1575	46.3	-
5	0.0670	0.5000	0.0335	-	-	1560	46.6	-
Average							49.2	

NOTES:
(1) Full-section tensile specimen unless noted.
(2) Filler wire 2319 aluminum alloy.
(3) Solution heat treat per MIL-H-6088D except heat treat temperature 985°F for 1 hour, cold water quench; aging at 325°F for 16 hours, air cool.

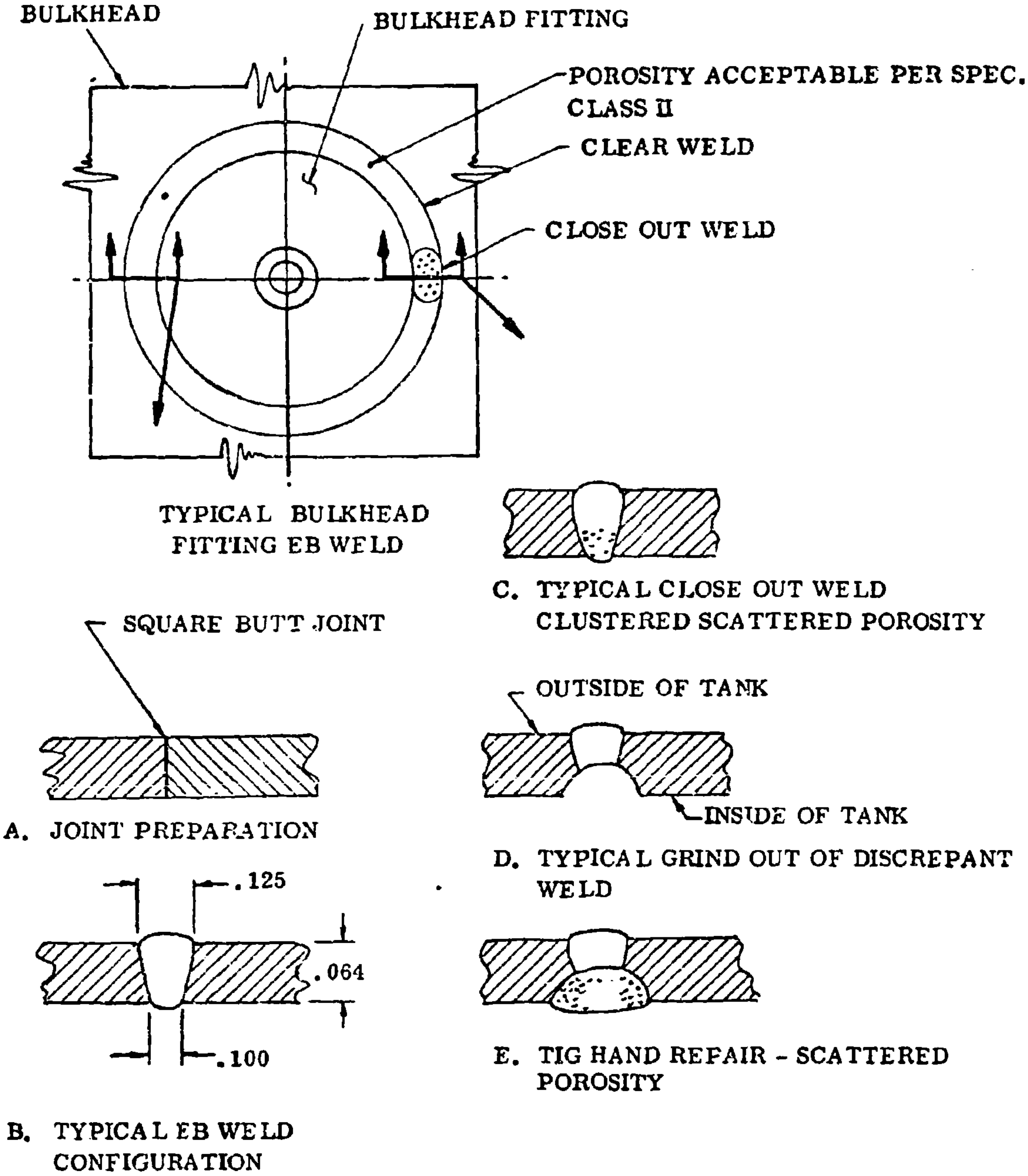


Figure 21. Aluminum Tank Fitting Weld

weld repairs could not be made successfully on defects to this schedule. The heat input during manual TIG repair appears to be causing vaporization of the cadmium and tin. Repairs by EB welding produce similar results.

A review of the weld process determined that weld dilution of the 2319 filler wire should be kept to a minimum. Minimum heat input into the parent material is mandatory to prevent vaporization of the cadmium and tin. A one "t" gap between the material to be welded was recommended by the material supplier. The gap criterion, however, was not compatible with the EB weld process. The electron beam must focus on the material to produce fusion. A 30-degree V-groove joint to a depth of 0.054 inch was prepared and welded to similate the one "t" gap approach with maximum amounts of filler wire. Radiograph and dye penetrant inspection showed a good weld. The specimens were tested for strength. Table XVI presents the results of the test. Simulated repair welds were made in the test specimens with good results. Figure 22 shows the joint preparation of the initial EB weld and weld repairs that can be repaired by TIG welding.

The bulkhead fill and drain fitting and cylinder section was scrapped. New larger diameter bulkhead fittings (-51) were solution heat treated and machined in-house. The cylinder sections were scrapped and used as weld schedule development test panels. The bulkheads were reworked to accommodate a larger 3-inch-diameter bulkhead fitting. The revised weld schedule used on the tanks are shown in Table XII.

3.3 TITANIUM FORMED BULKHEAD

The one piece formed bulkheads were procured from a vendor. The bulkhead blanks were alkaline cleaned prior to shipment. The alkaline cleaner consists of Oakite 90 in a concentration of 6 to 12 oz/gal at a temperature of 170 to 190°F. Cleaning consists of dipping in the alkaline solution for 5 to 15 minutes, water rinse for 3 to 5 minutes, and compressed-air dry for 10 to 30 minutes. The titanium blanks were encapsulated by the vendor. This was accomplished by sandwiching the blanks between two sheets of cleaned cold rolled steel welded around at the edges. The encapsulated titanium blanks were progressively formed and annealed, in stages, until the part was drawn to the finished depth. Three draw and anneal operations were required to form the finished bulkheads. The encapsulation material was stripped by the vendor prior to shipment.

The bulkheads were inspected for part count, visual checked for defects, dimensional check, and material identification number. A typical "as received" bulkhead is shown in Figure 23. Eighteen titanium blanks were shipped to the vendor from which 14 acceptable bulkheads were returned. The remaining four bulkheads were used in the initial die proofing and were partially formed or cracked. These bulkheads were scrapped.

Table XVI. Mechanical Properties of X-2021 Alloy Welded Tensile Specimens

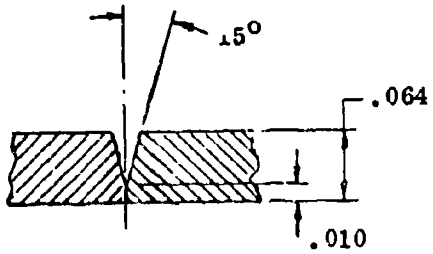
				Tensile Strength	
Specimen No.	Thickness	Width	Area	Lbs	KSI
6-2	.0660	.690	.0455	2435	53.5
6-4	.0660	.673	.0444	2355	54.8
6-6	.0660	.690	.0455	2420	53.2
		Average			53.8
7-2	.0660	.641	.0423	2325	54.9
7-4	.0660	.648	.0428	2150	50.2
7-6	.0660	.654	.0432	2250	52.1
		Average			52.4
8-3	.0670	.680	.0456	2415	53.0
8-5	.0670	.620	.0415	2035	49.0
8-7	.0670	.676	.0453	2270	50.1
8-9	.0670	.681	.0456	2570	56.4
		Average			52.1
6-3*	.0660	.710	.0469	1910	40.7

NOTES:

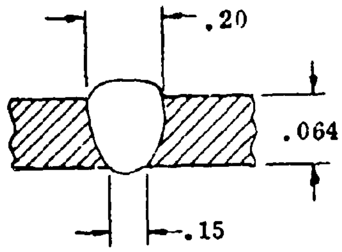
*Weld repair specimen.

1. All specimen failures occurred in the heat affected zone.

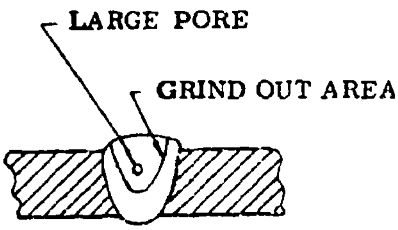
2. Tensile specimens were solution heat treated, welded and aged.



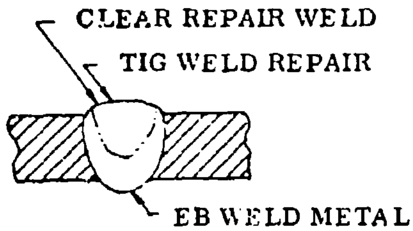
A. JOINT PREPARATION FOR EB WELD



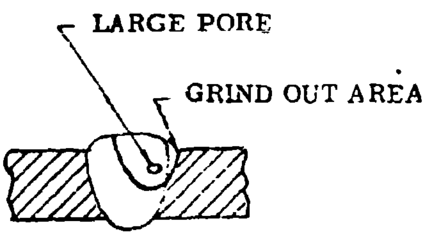
B. TYPICAL EB WELD FEED WIRE RATIO ≈ 3:1



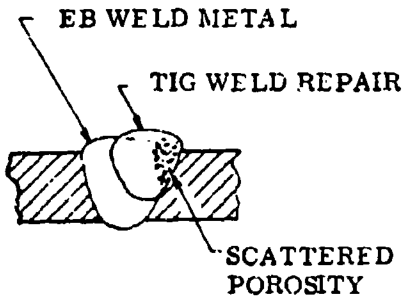
C. HAND TIG REPAIR



D. RESULT OF REPAIR (SATISFACTORY)



E. HAND TIG REPAIR



F. RESULT OF REPAIR (UNSATISFACTORY)

NOTE:
1. FILLER WIRE ~ 1/16 DIAMETER 2319 ALUMINUM ALLOY
2. EB WELD WIRE FEED TO TRAVEL SPEED ≈ 3:1

Figure 22. 2021 Aluminum Alloy EB Weld and TIG Repair Weld Development

Figure 23. "As Received" Titanium Bulkhead

The bulkheads were wet honed with Pumice #300 mesh, to remove iron oxide from the surface prior to trimming. Flange trimming and boring the 2.50-inch hole for the fill and drain fittings were accomplished with the turning fixture (68-59788-7 TUFX) on a lathe. The hole was made slightly undersize to allow for scraping prior to welding, Figure 24. Following inspection for dimensional check, the bulkheads were alkaline cleaned and acid pickled. The alkaline cleaning process consists of dipping in Oakite 90 (concentration of 6 to 12 oz/gal at a temperature of 170 to 190°F), rinse, and dry. The acid pickle operation consists of hand dipping for 5 seconds in an acid bath (20-34 oz/gal nitric acid, and 2-4 oz/gal hydrofluoric acid at room temperature), followed by a deionized water rinse and drying.

The deliverable tensile test coupons were processed identically to the bulkhead blanks except they were encapsulated prior to shipment and were not processed through the forming operation. The encapsulation was accomplished by sandwiching the test specimen with 1020 carbon steel and seam welding around the edges. Entrapped air was removed by cutting one corner of the carbon steel, placing the sample in the electron beam (EB) welding vacuum chamber, evacuating the chamber, and EB welding the cut edges. The welds were dye penetrant inspected to verify weld integrity. The tensile coupons were subjected to the same anneal cycle as the bulkheads.

Figure 24. Titanium Bulkhead Trimmed and Machined

Material gage of each bulkhead blank was measured at the center and edge of the blanks to provide data on bulkhead thinning during the hydroform process. These measurements are listed in Table XVII.

Table XVII. 6Al-4V Titanium Alloy Sheet Gage "As Received"

Sheet No.	Use	A* Edge (in.)	A* Center (in.)	B* Edge (in.)	B* Center (in.)	C* Edge (in.)	C* Center (in.)
1	Cylinder Skins	0.0415	0.042	-	-	-	-
2	Bulkhead Blanks	0.040	0.041	0.041	0.0415	0.0415	0.0415
3	Bulkhead Blanks	0.0415	0.0435	0.042	0.044	0.042	0.044
4	Bulkhead Blanks	0.042	0.043	0.0415	0.043	0.0415	0.043
5	Bulkhead Blanks	0.040	0.042	0.0405	0.042	0.042	0.042
6	Bulkhead Blanks	0.042	0.043	0.042	0.042	0.041	0.0425
7	Bulkhead Blanks	0.039	0.042	0.0415	0.0415	0.0415	0.042

*Three bulkhead blanks are obtained from each sheet of 0.040 by 36 by 96 inch material.

Dimensional checks made on the bulkheads after forming are shown in Figure 25. In general, the largest amount of thinning occurred in the area around the apex and knee. The thinning was as much as -0.007 inch and as little as -0.001 inch. The area around the bulkhead tangency decreased in gage by as much as -0.002 inch and increased in some by as much as +0.004 inch. The thinning, however, was generally as expected. The bulkhead diameters were measured with a "pi" tape. The close tolerance that was maintained is of significance in the follow-on welding that required close matching of diameters, cylinder to bulkhead.

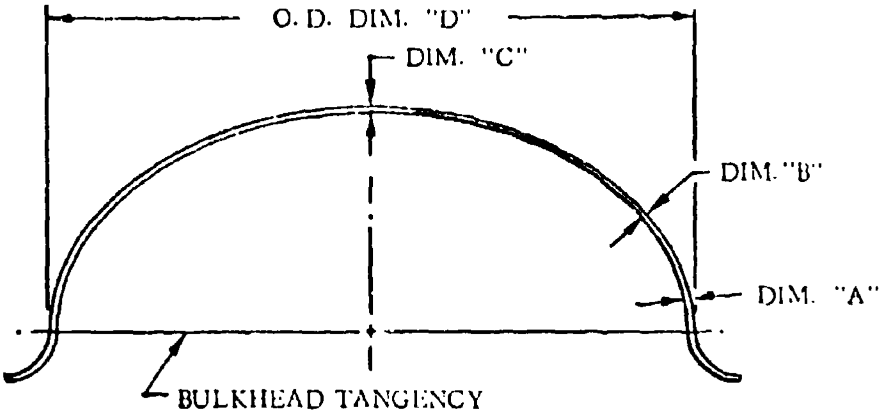
3.4 ALUMINUM-ALLOY FORMED BULKHEAD

The one piece formed bulkheads were procurred from a vendor. The bulkhead blank (26.50 inches in diameter) were commercially cleaned and solution heat treated prior to shipment. The commercial clean process requires that no evidence of foreign residue or contaminants is visible to the naked eye. The cleaning operation consists of a vapor degrease (trichlorethylene) followed by an alkaline clean, Oakite 164, 4 to 8 oz/gal at a temperature of 150 to 180°F, rinse and air dry. The bulkhead blanks were formed within 24 hours from heat treat.

No difficulties were encountered in forming 2021 in the solution heat treated condition after development of the hydroform schedule. (See Section 2.4.3.3.) The bulkheads were inspected for part count, visual checked for defects, dimensional check, and material identification number. Fifteen solution heat treated blanks (all the available material) were shipped to the vendor from which nine bulkheads of production quality were returned. The remaining six had varying degrees of wrinkles around the knuckle radius as a result of hydroform schedule development. (See Figures 26 and 27.) Hydroforming of X-2021 in the solution heat treated condition was found to be considerably superior to 6061 or 2219. The greater elongation (31 versus 22 percent) is sufficient to be able to hydroform in a single draw. The long natural aging time provides ample time for processing without age hardening.

Flange trimming and boring the 2.50-inch-diameter hole for the fill and drain fitting were accomplished with the turning fixture (68-59788-7 TUFX) on a lathe. Following inspection for dimensional check, the bulkheads were alkaline cleaned and deoxidized. The alkaline cleaning process consists of dipping in Oakite 164, 4 to 8 oz/gal at a temperature of 150 to 180°F, and water rinse. The deoxidizing consists of Wyandotte 2487 12 to 16 oz/gal and chromic acid 1.5 to 2.6 oz/gal at room temperature, water rinse, and air dry.

The deliverable tensile test coupon blanks were solution heat treated in the same load as the bulkhead blanks. The aluminum-alloy material gage was measured before and after hydroforming. (See Figure 28.) The maximum thinning occurred generally at the knee of the bulkhead. (See Figure 29.) The thinning range is between -0.0015 to -0.006 inch. The thinning at the apex was generally in the range of 0.001 to 0.004 inch while at the bulkhead tangency is in the range of 0.001 to 0.002 inch.



SERIAL NO.	DIM. "A" (INCHES)	DIM "B" (INCHES)	DIM "C" (INCHES)	DIM "D" (INCHES)
T-02	0.042	0.039	0.039	18.152
T-02	0.039	0.036	0.037	18.150
T-03	0.041	0.040	0.039	18.150
T-03	0.042	0.040	0.040	18.152
T-04	0.040	0.038	0.035	18.152
T-04	0.042	0.040	0.040	18.154
T-04	0.043	0.039	0.040	18.152
T-05	0.038	0.037	0.039	18.156
T-05	0.042	0.040	0.040	18.155
T-06	0.042	0.040	0.040	18.152
T-06	0.043	0.040	0.040	18.150
T-06	0.043	0.040	0.040	18.157
T-07	0.042	0.038	0.038	18.146
T-07	0.043	0.039	0.040	18.150
AVERAGE	0.0416	0.039	0.039	18.152

Figure 25. Titanium Bulkhead Thinning

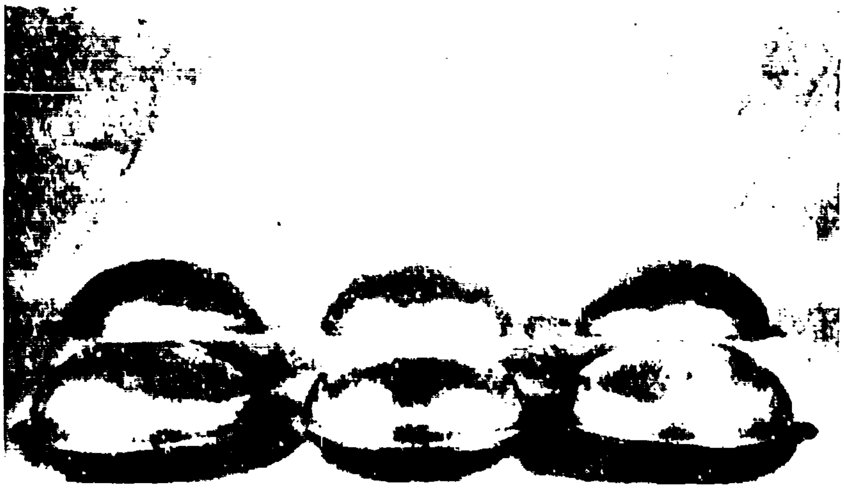
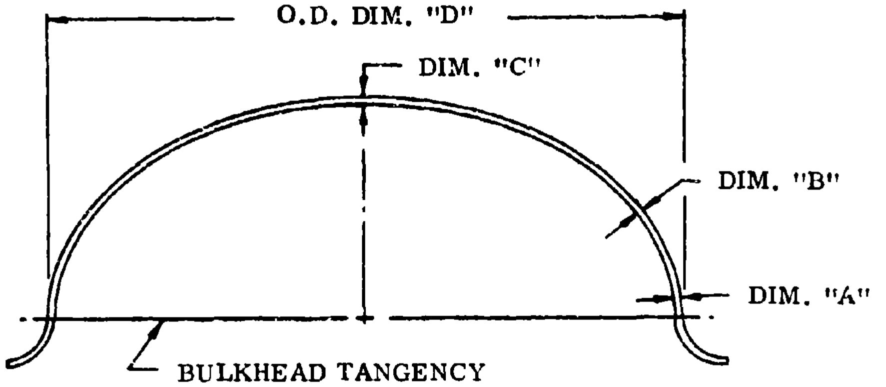


Figure 26. Lot of Wrinkled Bulkheads "As Received"

Figure 27. Typical Production Type Bulkhead



Sheet No.	Bulkhead No.	As Received Gage	Dim. "A" (Inches)	Dim. "B" (Inches)	Dim. "C" (Inches)	Dim. "D" (Inches)
A-01	1	.0670	.066	.061	.066	18.062
A-02	2	.0670	.065	.065	.065	18.071
A-02	3	.0670	.063	.064	.066	18.070
A-02	4	.0670	.063	.063	.065	18.065
A-03	5	.0665	.065	.061	.065	18.072
A-03	6	.0665	.066	.065	.065	18.079
A-03	7	.0670	.064	.062	.066	18.069
A-04	8	.0665	.065	.061	.065	18.076
A-04	9	.0670	.064	.064	.065	18.071
A-04	10	.0680	.065	.062	.065	18.068
A-05	11	.0675	.063	.062	.065	18.072
A-05	12	.0675	.066	.064	.066	18.070
A-05	13	.0670	.066	.064	.066	18.074
A-06	14	.0670	-	-	-	-
Average		.0670	.0647	.0629	.0654	18.078

Figure 28. Aluminum Bulkhead Thinning

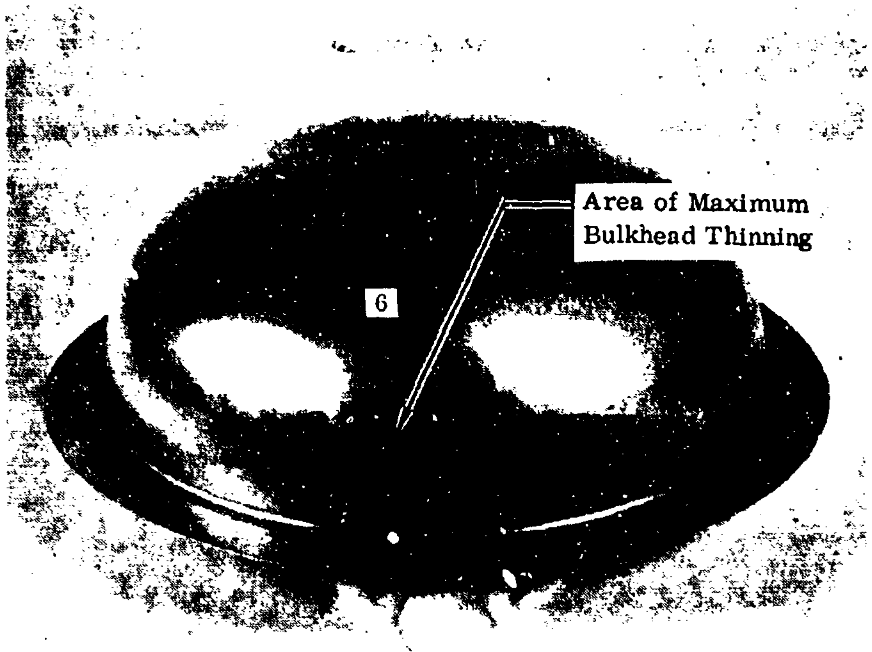


Figure 29. Bulkhead Thinning

The bulkhead diameters were measured with a "pi" tape and are shown in Figure 28. The maximum difference in diameter is 0.017 inch. This is indicative of the close tolerance that can be maintained by the hydroform process.

3.5 FILL AND DRAIN FITTINGS

The detail fill and drain fittings (68-59788-15 titanium and -25 aluminum alloy) were procurred from a vendor. The materials, 2.75-inch-diameter by 20-inch-long bar stock titanium alloy and 1.0- by 24- by 36-inch X-2021 aluminum alloy plate, were supplied by Convair. The chemical and mechanical properties of the material are shown in Section 2.4.1. The fittings were machined to the design provided by Convair. The seal groove and threads are per MS27854-08 and MS27859-08. The aluminum alloy plate material was solution heat treated prior to shipment. The -51 aluminum-alloy fitting was machined by Convair and was identical in design to the -25 aluminum-alloy fitting except for the larger flange diameter (3.00-inch versus 2.50-inch diameter). The -51 fittings were used to replace the -25 fittings as a result of the rework required on the aluminum-alloy tanks.

3.6 CYLINDER SECTION

The aluminum and titanium sheet stock was roll formed into an approximate 18.0-inch-diameter cylinder and trim fitted to two matching bulkhead subassemblies with allowances for longitudinal weld shrinkage.

The sheet stock was sheared oversize and roll formed into the 18.0-inch-diameter cylinder shape. The final cylinder diameter was established by match-fitting with paired bulkhead subassemblies. The mating edges were draw filed a minimum of one "t" on both edges to eliminate shear cracks from the trimming operation. In addition, the aluminum cylinder mating edges were provided with a V-groove with an included angle of 30 degrees and 0.054 inch deep.

After this operation was completed the matching bulkheads and cylinder sections were tagged. The cylinder skins were then chemically cleaned. The titanium cylinders were deoxidized with Oakite 90 in a concentration of 6-8 oz/gal at a temperature of 170 to 190°F and then acid pickled in a mixture of nitric acid 20 to 34 oz/gal and hydrofluoric acid 2-4 oz/gal. The aluminum cylinders were deoxidized in a solution consisting of Wyandotte 2487 in a concentration of 12 to 16 oz/gal and chromic acid 1.5 to 2.6 oz/gal, water rinse, then air dried.

The cylinder butt-joints were then hand scraped and prepared for welding. The part was placed in a weld fixture (68-59788-9 AU-19 WLFX) and clamped. (See Figure 14.) The total unit including the weld fixture was installed in the EB welding vacuum chamber. Welding was accomplished using the validated weld schedule discussed in Section 3.3.1.

The finished EB welded cylinders were radiographic and penetrant inspected. The radiograph standards were NAS1514 Class II for the titanium alloy and MIL-R-45774 Class II for the aluminum-alloy cylinders. The penetrant inspection was per MIL-I-6866. The cylinders were then trimmed to net width on the trim fixture (68-59788-9 AU-19).

3.7 TUBE SUBASSEMBLY

The tube subassembly (68-59788-45) for the titanium tanks consists of:

a. MS27852-08 nut.

b. MS27853-08 plain flange.

c. 68-59788-49 tube.

d. MS20819-8J sleeve.

e. AN818-8C nut.

The tube subassembly (68-59788-43) for the aluminum tank consists of:

a. MS27857-08 nut.

b. MS27858-08 plain flange.

c. 68-59788-47 tube.

d. MS20819-8D sleeve.

c. AN818-8D nut.

All fittings for the tube subassemblies are standard stock items and were purchased from a vendor to the applicable fitting specifications.

The tubing used on the -45 subassembly is 1/2-inch-outside diameter by 0.065-inch wall, 321 annealed stainless steel and procurred to MIL-T-8808. The -43 tube subassembly for the aluminum tanks is 1/2-inch outside diameter by 0.035-inch wall, 6061-T6 aluminum alloy and procurred to MIL-T-7081.

The tubing was flared per MS33584 and cut to the 3.60-inch lengths. Welding was accomplished on the EB welder using a weld fixture (68-59788-43 AU-45) to the approved weld schedule. (See Section 3.2.) The tubes were radiograph and penetrant inspected and leak checked along with the bulkhead subassembly leak check.

3.8 BULKHEAD SUBASSEMBLY

The titanium bulkhead subassembly (68-59786-13) consists of the fill and drain fitting (-11) welded into the apex of the formed and machined bulkhead (-7). The aluminum bulkhead subassembly (68-59788-23) consists of the fill and drain fitting (-51) welded into the apex of the formed and machined bulkhead (-17). The fusion EB butt weld was made using a weld fixture (68-59788-13 and -23 WLFX) setup shown in Figure 30. The titanium bulkhead weld joint interface was scraped and cleaned with oxylene prior to welding. The aluminum bulkhead weld joint was draw filed and scraped prior to welding. The fitting and bulkhead were clamped in the fixture, and the entire assembly was mounted on the turntable in the EB weld chamber. The weld joint is optically aligned under the beam by rotating the turntable and positioning the fixture. The EB gun is focused to the work piece to the approved schedule height (see Section 3.2). Welding is accomplished by rotating the turntable under the beam. The operation is completely automatic once the machine settings are made. Minor variations in position tolerances of the weld joint under the beam are corrected for by the automatic seam tracker.

The completed bulkhead subassembly weld, Figure 31, was radiograph inspected, dye penetrant checked, and leak checked. The titanium bulkhead subassembly welds were radiograph inspected to the standards of NAS1514 Class II and penetrant inspected to the standards of MIL-R-6866 Type I. The aluminum bulkhead subassembly welds were

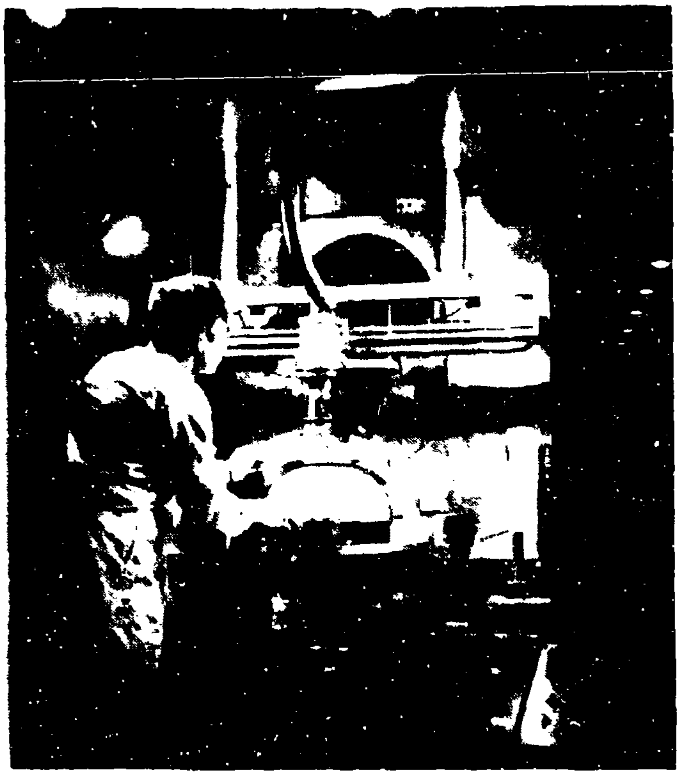


Figure 30. Titanium Bulkhead Subassembly Welding

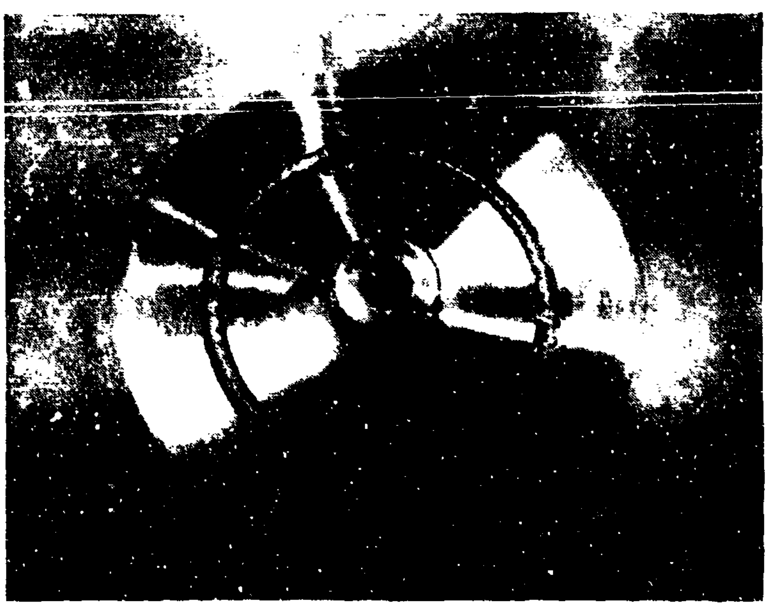


Figure 31. Typical Titanium Fitting Weld

radiograph inspected to the standards of MIL-R-45774 Class II and penetrant inspected to MIL-R-6866 Type II. The bulkhead weld leak-check was accomplished with a helium mass spectrometer using the bulkhead leak-check test tool 68-59788-13 AU-23 TSTO to blank off the weld area. (See Section 4.1.) Acceptable bulkhead subassemblies were then processed for final tank assembly.

3.9 TANK FINAL ASSEMBLY

The titanium tank final assembly (68-59788-1) consists of welding together a cylinder section with its two mating bulkhead subassemblies. The tank weld joints were scraped and cleaned with oxylene prior to assembly. The cylinder skin was aligned to the bulkhead with external metal straps. The alignment straps have 3/8-inch holes spaced on one-inch centers. This allows EB tack welding to be accomplished at the two girth weld butt joints while the parts are held in alignment. Two threaded fittings are screwed on the tank fittings. The threaded fittings are held by the head and tail stock in the chamber. This allows rotation of the tank under the electron beam.

The tank with weld fixturing strap and the two threaded fittings installed is placed in the EB weld chamber and chucked to the head and tail stock. The weld joint is optically aligned under the beam fore and aft by moving the head and tail stock carriage. The lateral alignment is accomplished by moving the EB welding head. The EB gun is focused to the workpiece to the approved schedule height. (See Section 3.2.) After tack welding, the weld fixture straps are removed and the final fusion weld accomplished using the established schedule (Figure 32). No filler wire was required for the EB welding. The final fusion welding operation is completely automatic once the machine settings are made. Minor variations in lateral position tolerance of the weld joint under the beam are compensated by the automatic seam trackers. The seam tracker maintains beam welder focus on the weld joint.

The tank close-out welds were radiograph and penetrant inspected prior to leak check and hydrostatic testing. The radiographic inspection was to NAS1514, Class II, and penetrant inspection to MIL-I-6866, Type I. A typical completed titanium alloy tank is shown in Figure 33.

The aluminum tank final assembly (68-59788-3) consists of welding together the -19 cylinder section with its two mating -23 bulkhead subassemblies. The tank weld joints were cleaned then scraped or draw filed prior to assembly in the weld fixture. The same weld fixture used on the titanium tank assembly was used. The fixturing strap was modified and provided with 0.38-inch-wide by six-inch-long holes spaced along four quadrants of the circumference. The holes allow a continuous six-inch-long EB tack weld to be accomplished at the two girth butt joints while the part is held in alignment. The same setup procedure used for the titanium tank final assembly was used for alignment of the aluminum tank assembly in the chamber.

Figure 32. Typical Final Close-out EB Welding

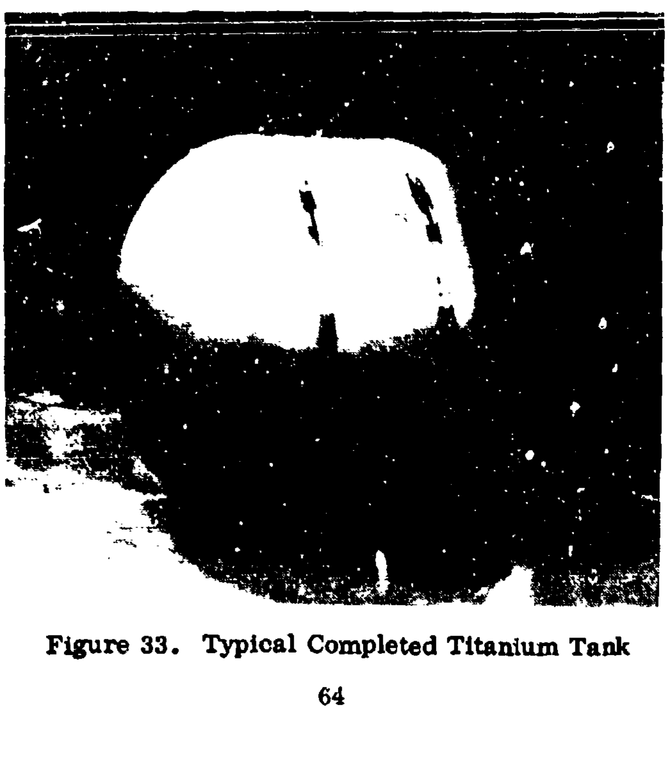


Figure 33. Typical Completed Titanium Tank

Some joint alignment problems were encountered in the tack welding. The differential expansion of the cylinder to bulkhead caused mismatch up to one "t". The mismatch problem was resolved by using eight tack welds three inches long, equally spaced, rather than the initial four tack welds six inches long. This prevented the gathering of the material as the tack welding progressed.

The weld fixturing strap was removed prior to final close-out fusion welding. Welding was accomplished to the approved schedule, Table XII, using 2319 filler wire.

The tank close-out welds were radiographed and penetrant inspected prior to leak check. The radiograph inspection was to MI -R-45774, Class II, and penetrant inspection to MIL-R-45774, Class II, and penetrant inspection to MIL-I-6866, Type II. A typical completed aluminum alloy tank is shown in Figure 34.

Following the leak check discussed in Section IV the tanks were aged. Aging was accomplished at 325°F for 16 hours, then air cooled as recommended by the material supplier. Tank 5 was inadvertently aged at 350°F for 7-1/2 fours, 325°F for one hour, then air cooled. Deliverable Tensile Coupon A01L was in the same furnace load with Tank 5.

Tensile tests were run on two specimens aged in the same load as Tank 5. A comparison of tensile test data is shown in Table XVIII with specimens aged at 325°F for 16 hours. The data reveals that Tank 5 was slightly overaged. A loss of up to 7.2 percent in yield strength is indicated.

Figure 34. Typical Completed Aluminum Tank

Table XVIII. Mechanical Property Tests for Aged X-2021 Aluminum Alloy

RECOMMENDED AGE

Sample No.	Thickness (inch)	Width (inch)	Area (in.^{2})	Yield (0.2% Offset)		Ultimate		Elongation (% in 2 inches)
				(lb)	(ksi)	(lb)	(ksi)	
A07T								
1	0.0646	0.4990	0.03223	2050	63.6	2310	71.7	9.5
2	0.0658	0.4950	0.3257	2075	63.7	2345	71.9	9.0
3	0.0656	0.4964	0.03256	2100	64.5	2335	71.7	9.5
A08T								
1	0.0653	0.04951	0.03233	2025	62.6	2320	71.8	9.5
2	0.0653	0.4958	0.03237	2030	62.7	2345	72.4	9.0
3	0.0655	0.4954	0.03245	2035	62.7	2335	71.9	9.0
Average					63.3		71.9	9.3
Typical 2021 - T62 Properties					65		75	8.0

Note: Solution heat treat per MIL-H-6088H except heat treat temperature 985°F for 1 hour; water quench; age at 325°F for 16 hours, air cool.

NON-STANDARD AGE

Sample No.	Thickness (inch)	Width (inch)	Area (in.^{2})	Yield (0.2% Offset)		Ultimate		Elongation (% in 2 inches)
				(lb)	(ksi)	(lb)	(ksi)	
A01L								
1	0.0659	0.4973	0.03277	1918	58.5	2180	66.5	9
2	0.0663	0.4968	0.03294	1945	59.1	2225	67.6	10
Average					58.8		67.0	9.5

Notes: Solution heat treat, water quench; age at 350°F for 7-1/2 hours, 325°F for 1 hour, air cool.
Solution heat treat per MIL-H-6088H except heat treat temperature 985°F for 1 hour, water quench; age at 350°F for 7-1/2 hours, 325°F for 1 hour, air cool.

3.10 WELD REPAIRS

3.10.1 TITANIUM TANK WELD REPAIRS. Weld repairs on the titanium tanks were substantially greater than anticipated. Table XIX provides a composite of all welding accomplished on the titanium tanks with the number of weld repairs required.

The major problem was determined to be the threaded shaft used to fixture the tack welded tank in the EB welding turning fixture. The shaft did not provide adequate vertical and lateral alignment with the EB welding beam causing incomplete fusion and sharp suck backs. The tool was modified prior to welding Tank 5. The modification consisted of two fittings that were threaded on the bulkhead end fittings rather than the threaded shaft that passed through the tank. This provided greater lateral and vertical support, thus maintaining closer alignment of the beam to the weld joint interface. The significant improvement in the weld quality was evident by the results of the radiographic inspection shown.

Weld repairs were accomplished by routing or grinding out of the discrepant weld area. The tanks were purged with helium, hand TIG welded using 6Al-4V titanium filler wire then resubmitted for x-ray. All titanium tanks have passed radiographic inspection to the standards of NAS 1514 Class II standards. The tanks were given a dye penetrant inspection per MIL-I-6866 Type C. No problems were encountered in the penetrant inspection.

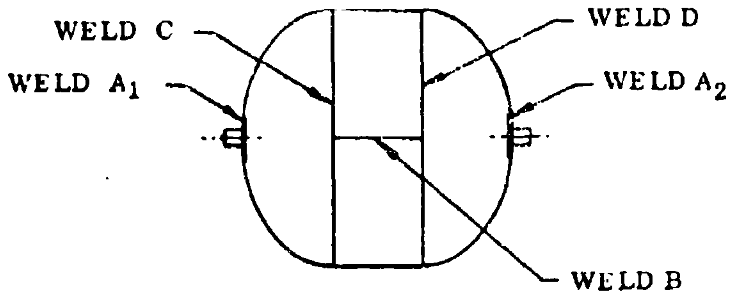
3.10.2 ALUMINUM-ALLOY TANK WELD REPAIRS. Table XX presents the results of the weld defects encountered throughout the aluminum-alloy tank fabrication program. All defects shown are subsequent to the new weld schedule development where the maximum amount of 2319 aluminum-alloy filler wire was used. All weld repairs were accomplished by EB welding except where noted.

Weld repairs on Tanks 1, 2, and 3 were of routine nature. The discrepant areas were routed and EB repair welded. (See Figures 35 and 36.) In most instances weld repairs were successful on the first repair.

The close-out hoop weld of Tank 4, weld "C", Table XX, produced a bad weld with numerous defects. During the welding operation the beam was improperly positioned over the weld joint resulting in linear porosity throughout the circumference of the tank. The entire weld was removed by machining a weld joint V-groove and was completely rewelded.

Tank 5 presented the most difficulties in welding. Excessive porosity, undercutting, and numerous cracks were found in the welds. Eight successive weld repairs were made on weld C while six successive weld repairs were made on weld D. Cracks and unacceptable porosity was still present, and the tank was scrapped and remade. One bulkhead subassembly from the scrapped tank was salvaged and mated to an available

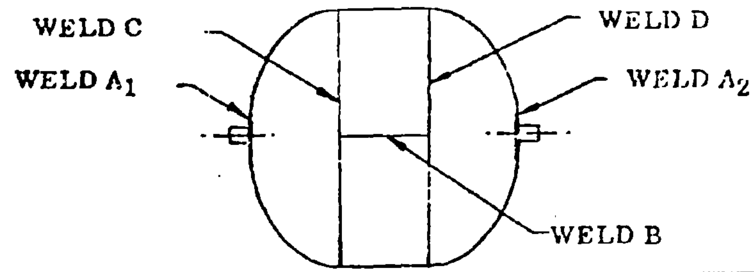
Table XIX. Titanium Tank Weld Repairs



Titanium Tank No.	Weld No.	WELD RADIOGRAPH Weld A_1	Weld A_2	Weld B	Weld C	Weld D
1	Original	A	A	A	IF	CR, SB
	1st repair				IF	A
	2nd repair				SB*	
	3rd repair				SB*	
	4th repair				A	
2	Original	IP	A	A	IF, LP, SB	A
	1st repair	A			SP, IP	
	2nd repair				LP, IF	
	3rd repair				IF	
	4th repair				CR	
	5th repair				A	
3	Original	A	CR	A	LP	A
	1st repair		A		LP*	
	2nd repair				A	
4	Original	A	CR, SP	LP, IF	SB, IF	LP, IF, SB
	1st repair		CR, IF	A	SB	SB
	2nd repair		A		SB	SB
	3rd repair				SB	SB*
	4th repair				A	A
	5th repair					
5	Original	LP, IP	LP, IP	LP	A	SB
	1st repair	IP	A	LP		SB*
	2nd repair	A		A		A
6	Original	A	A	A	A	A
7	Original	A	IP	A	SB*	A
	1st repair		A		A	

A - Acceptable Weld
LP - Linear Porosity
IF - Incomplete Fusion
CR - Cracks
SB - Suck-back (Sharp)
* - Small Localized Defect
SP - Scattered Porosity
IP - Large Individual Porosity

Table XX. Aluminum-Alloy Tank Weld Repairs



ALUMINUM ALLOY TANK NO.	WELD REPAIR NO.	WELD A_1	WELD A_2	WELD B	WELD C	WELD D
1	Original	A	.035,.040IP	A	.035 to .045IP(7)** .035 CP,.010 CR	.035 to .065IP(9)** .035IP,.015 CR,.080IP
	1st Repair				.060,.035IP, CP	.035 to .045IP(8),SP,CP**
	2nd Repair				CR, IP	
	3rd Repair				SP**	
2	Original	A	A	A	.035 to .040IP(3)**,.055IP CR	.035 to .045IP(5)**
	1st Repair				A	
3	Original	A	.055IP**	A	.045IP**	.035 to .050 IP(3) LP(2)**, CP..035, .090,.055IP,.125, .070IP
	1st Repair					A

A - Acceptable Weld
LP - Linear Porosity
IF - Incomplete Fusion
CP - Clustered Porosity
** - Engineering Buy-Off
CR - Cracks
SB - Suck-back (Sharp)
* - Small Localized Defect
SP - Scattered Porosity
I P - Large Individual Porosity

Table XX. Aluminum-Alloy Tank Weld Repairs, Contd

ALUMINUM ALLOY TANK NO.	WELD REPAIR NO.	WELD A_1	WELD A_2	WELD B	WELD C	WELD D
4	Original	.035 IP**	.100 CR, .040 IP	.045, .085 IP	Numerous, Re-Machine Groove for New Weld	.035 to .045 IP, SP**, .105 IP, CR
	1st Repair		A	.055 IP	.035 to .065 IP (6), SP**, CR	.035 to .065 IP(3), SP** CR(2)
	2nd Repair			A	.035 to .055 IP(4)**	.070 IP, .090 IP
	3rd Repair					A
5	Original	.040, .040, .040 .050 IP	.045, .050 IP**	A	Numerous, Re-Machine Groove for Reweld	.035 to .060 IP(6), LP** CP
	1st Repair	A			.035 to .065 IP(6), LP** .075, .110 IP	.035 IP**
	2nd Repair (TIG)				.035 IP(2), LP**	
6	Original	A	.035, .035, .065 .100 IP	A	.035 IP**, CR(9) & IP	SP, .035 IP**, CR, IP
	1st Repair		A		IP, CR(5)	.035, .085 IP, CR
	2nd Repair				IP, CR(5)	LP, .040 IP**
	3rd Repair				IP, CR(5)	
	4th Repair				IP, CR(1)	
	5th Repair				IP, CR(1)	
	6th Repair				IP, CR(1)	
	7th Repair				.070, .035, .040, .050 IP**	

A - Acceptable Weld
LP - Linear Porosity
IF - Incomplete Fusion
CP - Clustered Porosity
** - Engineering Buy-Off

CR - Cracks
SB - Suck-back(Sharp)
* - Small Localized Defect

SP - Scattered Porosity
I P - Large Individual Porosity

Figure 35. Typical Weld Repair Routing

Figure 36. Typical Weld Repair

spare bulkhead, (previously failed bulkhead leak check which was subsequently repaired). A new cylinder section was fabricated and then mated to the two bulkheads. Rewelding of the new Tank 5 resulted in unacceptable linear porosity throughout the length of weld C. The problem was due to the automatic seam tracker missing the machined V-groove. The weld bead was again remachined and rewelded. Two weld repairs were made on weld C including a TIG weld repair before an acceptable tank was produced.

Tank 6 produced nine cracks and some individual porosity in a localized 12-inch length of weld C. Seven weld repairs over the localized area were required before all cracks could be removed. This resulted in some tank flattening in this area.

Few weld repairs were required on the fill and drain boss welds and the cylinder longitudinal butt welds. Substantial weld repairs were required on the tank close-out hoop welds. The differences in the weld quality can be attributed to the backup chill bars used in the former welds. The tank close-out hoop welds were accomplished without internal tooling, thereby causing vaporization of the cadmium-tin resulting in substantial amounts of porosity and cracks. Part of the problem can also be attributed to the automatic seam tracker.

The lack of hard tooling in the final close-out weld caused the V-groove butt joint to wander laterally and vertically under the beam. The excessive motion prevented the automatic seam tracker from maintaining the proper position under the beam. Rewelding also induced warpage of the bulkheads sufficiently to aggravate the tracking problem.

3.11 TANK MATERIAL, X-RAY CORRELATION, AND IDENTIFICATION

The storability test program is primarily concerned with evaluating the weld integrity of typical aerospace tanks after long-term storage of various liquid propellants. To provide comparison of the storability performance with properties of the unprocessed materials, test coupons were required. A system of serial part numbers was required such that it would be possible to determine from which particular sheet material a tank part or a test coupon was taken. The following identification system was used on the tensile coupons.

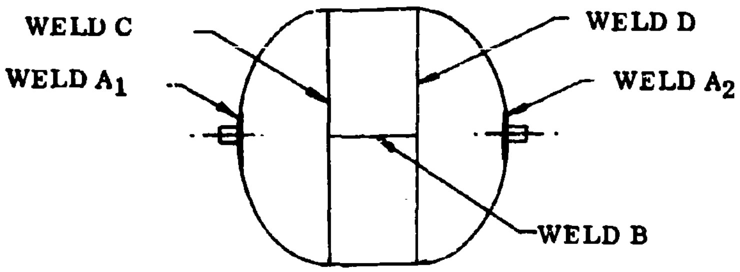
The two different materials from which the tanks are fabricated were identified as follows:

A — 2021 aluminum alloy
T — 6Al-4V titanium alloy

A two-digit number was added for the material sheet number, followed by a "T" or "L" identifying the transverse or longitudinal grain direction. The butt fusion welded test coupons were identified by the addition of W.

Each part of the finished tank assembly was identified externally by a drawing number, part number, and material sheet number. In addition, Table XXI and XXII provide the correlation of the material sheet number, weld, final cleaning, and X-ray numbers of each tank. The radiographic number of the stainless steel tube subassembly is 2X9080 and 2X9062. The radiographic number of the aluminum-alloy tube subassembly is 3X9042.

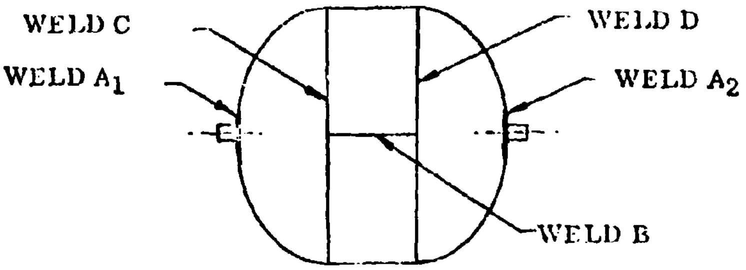
Table XXI. Titanium Tank Weld and Radiograph Correlation



Tank No.	Tank Cleaning	Weld	Sheet No.	Radiograph No.
1	Hydrazine	A_1	6	2X9056
		A_2	3	2X9068
		B	1	3X9067
		C, D	6-1, 3-1	4X9033
2	Hydrazine	A_1	3	2X9052
		A_2	5	2X9057
		B	1	3X9062
		C, D	3-1, 5-1	4X9037
3	N_2O_4	A_1	7	2X9047
		A_2	3	2X9066
		B	2	4X9001
		C, D	7-2, 3-2	4X9040
4	Hydrazine	A_1	6	2X9055
		A_2	4	2X9063
		B	1	3X9063
		C, D	6-1, 4-1	4X9045
5	N_2O_4	A_1	4	2X9067
		A_2	2	2X9065
		B	1	3X9065
		C, D	4-1, 2-1	4X9052
6	N_2O_4	A_1	7	2X9064
		A_2	2	2X9054
		B	1	3X9066
		C, D	7-1, 2-1	4X9053
7*		A_1	5	2X9059
		A_2	4	2X9053
		B	1	3X9064
		C, D	5-1, 4-1	4X9074

*Tank failure during hydrostatic test, scrap tank.

Table XXII. Aluminum-Alloy Tank Weld and X-Ray Film Correlation



Tank No.	Tank Cleaning	Weld	Blkhd. or Cyl. No.	Sheet No.	Radiograph No.
1	Hydrazine	A_1	10	3	3X9022
		A_2	13	6	3X9025
		B	2	6	5X9015
		C, D	-	6-1, 6-6	5X9048
2	N_2O_4	A_1	3	1	3X9015
		A_2	12	5	3X9024
		B	3	7	5X9014
		C, D	-	1-7, 5-7	5X9049
3	N_2O_4	A_1	6	2	3X9018
		A_2	8	3	3X9020
		B	1	8	5X9012
		C, D	-	2-8, 3-8	5X9050
4	N_2O_4	A_1	1	5	3X9011
		A_2	4	3	3X9016
		B	6	7	5X9017
		C, D	-	5-7, 3-7	6X9004
5	Hydrazine	A_1	9	2	3X9021
		A_2	2	4	3X9014
		B	7	8	6X9030
		C, D	-	2-8, 4-8	6X9037
6	Hydrazine	A_1	11	5	3X9023
		A_2	14	6	5X9032
		B	5	7	5X9016
		C, D	-	5-7, 6-7	6X9009

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SECTION IV

TANK TESTS

The 12 aluminum and titanium alloy tanks were hydrostatic proof pressure tested and leak checked prior to delivery to AFRPL. The leak-check methods selected were based on the leak detection sensitivity and the ability to locate and repair leaks once they had been detected. The methods available are the bubble fluid, hand probe, vacuum leak check with mass spectrometer, and vacuum chamber leak-check methods. The range of sensitivity of these methods are:

	Method	Range (scc/sec)	Remarks
1.	Bubble fluid	1×10^{-4} to 1×10^{-5}	Poor sensitivity, easy to locate leak.
2.	Hand sniffer probe	1×10^{-6} to 1×10^{-7}	Good sensitivity, locates general area of leakage.
3.	Vacuum leak check	1×10^{-7} to 1×10^{-8}	Excellent sensitivity, excellent ability to locate leak.
4.	Vacuum chamber	1×10^{-9} to 3×10^{-10}	Excellent sensitivity, gross leak detection, does not locate leak.

All methods indicated were used during various phases of tank fabrication and test.

The bubble fluid leak-check method is the least sensitive of the four methods; however, it is a useful method in detecting major flaws in welded joints that are not readily visible under x-ray examination. The test setup is inexpensive, quick, and provides a good method of locating large leakages. The bubble fluid leak-check method was used after final closeout welding and prior to hydrostatic test. This procedure was selected to preclude detection of leakages during the hydrostatic test, which would otherwise require tank drying prior to repair. The bubble fluid leak check was used essentially as a precautionary measure to provide some confidence in the leak tight integrity of the as fabricated article.

The hand sniffer probe method provides a greater sensitivity than the bubble fluid leak-check method (1×10^{-6} to 1×10^{-7}). However, it is a time consuming method when detecting in the range of 1×10^{-7} scc/sec. The problem of utilizing the sniffer probe method lies in the sensitivity. The standard "sniffer" probe method when used with proper care is generally sensitive to approximately 1×10^{-6} scc/sec. This leaves the range from the vacuum chamber leak detection range to the sensitivity of

the sniffer probe leak rate. The leak detector manufacturer has stated that a sophisticated sniffer method can be sensitive in the range of 1×10^{-7}. Extreme care is required when detecting in this range and a dry tank is mandatory. The hand sniffer probe method was used on the aluminum-alloy tanks prior to aging. The sniffer probe was also used during the vacuum chamber leak checks to locate general areas of leakage, particularly around the fittings.

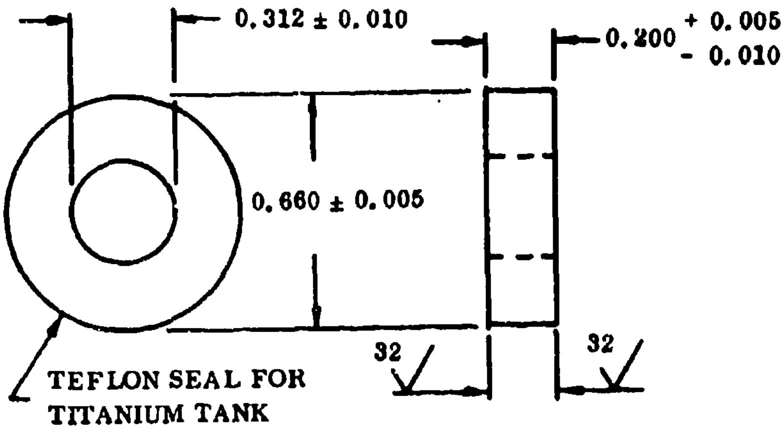
The vacuum leak-check method is one of the best methods of leak checking. It provides the combined sensitivity with the ability to locate and repair leaks. The method involves pulling a high vacuum inside the pressure vessel with a mass spectrometer leak detector while spraying helium on the exterior of the tank. The method provides the sensitivity of the helium mass spectrometer and also the most sensitive way of locating any leaks. This method, however, could not be used on the completed tanks as they were not designed to withstand compression loading. The leak-check method was used in establishing leak tight integrity of the bulkhead welds.

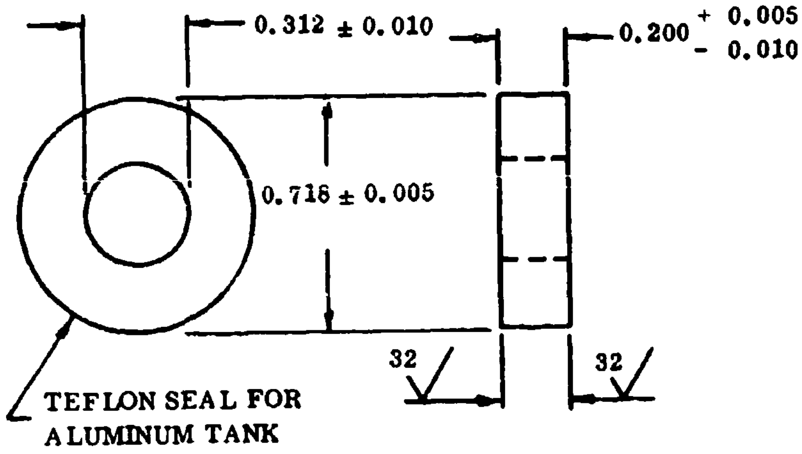
The vacuum chamber method with a helium mass spectrometer provides the highest sensitivity in leak detection. The detection method, however, provides gross leakages only with no detection capability. The vacuum chamber method was used on all delivered articles to certify that the tanks were within the maximum acceptable single leakage rate of 1×10^{-7} scc/sec.

A deliberate step-by-step test procedure was followed throughout the fabrication program to minimize tank rework after final assembly.

Teflon washer seals, Figure 37, were fabricated and used in place of MS27855-08 and MS2786-08 metal seals during all proof pressure tests and preliminary helium leak checks. The metal seals were installed in the final leak check, vacuum chamber leak check, prior to tank delivery. The teflon seals were used primarily to reduce program costs. The metal MS27855-08 and MS27860-08 seals are not reusable and expensive. Since substantial quantities of seals were required for all tests, the teflon washer seal was designed and fabricated for use in the preliminary leak tests. Teflon seals of this type have been used in other fitting applications and have proved satisfactory.

Tests accomplished on the 15-gallon tank program, using the teflon seals, indicate that there are distinct advantages together with meeting all leakage requirements for the particular setup. These advantages: 1) the teflon washers are easy to fabricate and inexpensive. The seals were fabricated from rod stock, turned on a lathe, drilled, and cut to size. 2) The metal sealing surface of the plain and threaded flange was not subject to nicks, scratches, and indentation from repeated installation and removal. This is particularly true of the aluminum fittings where the soft aluminum is particularly susceptible to scratches from removal of old seals. 3) The MS seals can only be used once and need be discarded. The same set of teflon seals were used for both the leak checks and hydrostatic tests. No leakage problems were encountered when adequate torque was applied to the nut (200-240 inch-pounds).





ALL DIMENSIONS ARE INCHES

Figure 37. Teflon Seal for Aluminum and Titanium Tanks

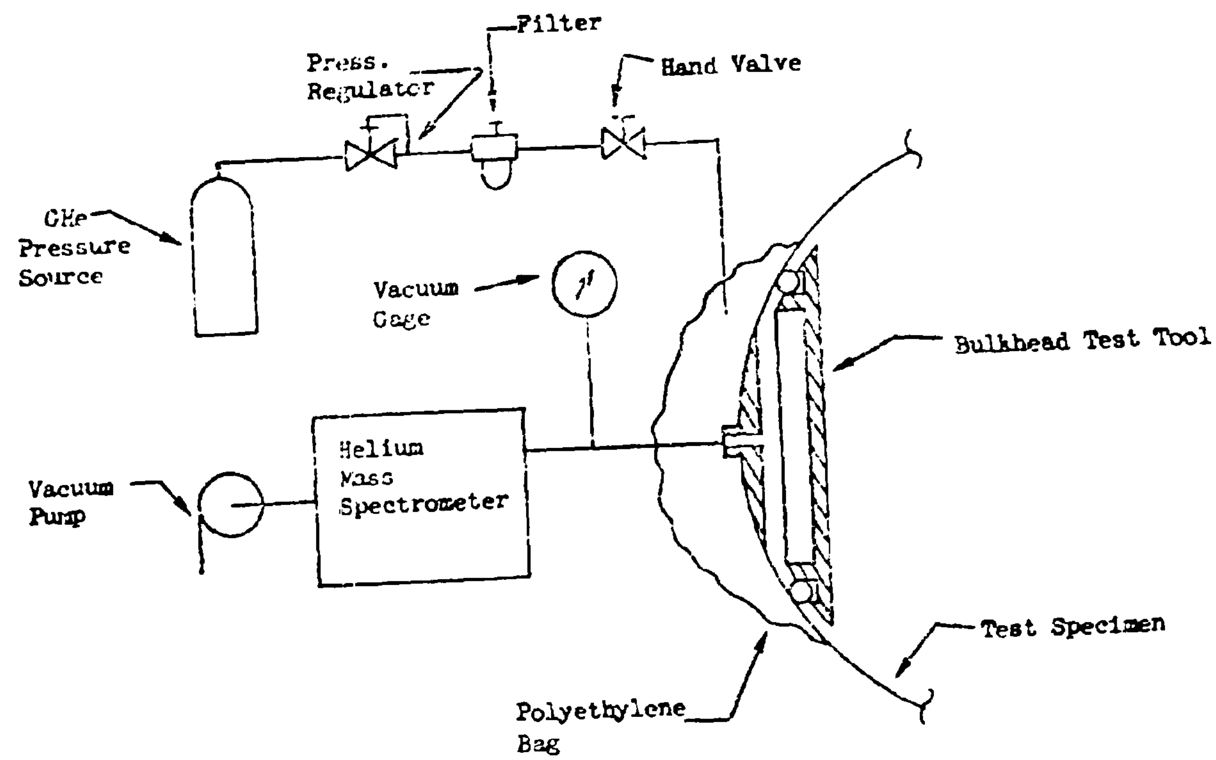


Figure 38. Bulkhead/Fitting Leak Test Schematic

4.1 BULKHEAD AND TUBE SUBASSEMBLY LEAK CHECK

Fourteen titanium bulkhead subassembly (68-59788-13) and 13 aluminum-alloy bulkhead subassembly (68-59788-23) fitting welds were helium leak checked prior to final assembly using the test setup shown in Figure 38. The purpose of this preliminary leak check was to detect defective welds or leakage in the early stages of fabrication where repairs can be affected with the least difficulty. The test also served as a leak check of the tube subassembly (68-59788-43 and -45) welds.

The bulkhead and the tube subassembly leak test procedure consists of placing the bulkhead leak-check test tool inside the bulkhead test specimen so that the bulkhead around the welded area may be evacuated. The tube subassembly was installed using a teflon seal in place of the standard MS27855-08 or MS27860-08 seals. The outside area around the bulkhead fitting weld and tube subassembly weld was bagged with polyethylene film. The bulkhead cavity was evacuated to 1×10^{-4} mmhg. While maintaining the vacuum, the polyethylene bag covering the welded fitting and tube subassembly was flooded with pure helium gas, Figure 39. No leakages were detected from the 14 titanium bulkheads. Twelve of the 13 aluminum bulkheads tested indicated no leakage. A small pin-hole leak was detected in one aluminum bulkhead. Leakage occurred at the closeout weld. The leakage was repaired with no difficulty.

Figure 39. Bulkhead/Fitting Leak Testing

Minor problems were encountered with the teflon seal being used in place of the MS27855-08 seal. Leakage occurred initially around the teflon seal but the problem was quickly resolved. The fitting nut was torqued to 200-240 inch-pounds to stop all leakage. The standard torque for the MS27850 installation is 490 to 555 inch-pounds. Reusing the teflon seals in the helium leak check did not prove practical. The residual helium on the washers indicated erroneous helium leakage.

4.2 PRE-PROOF PRESSURE LEAK CHECK

Prior to submitting the tanks to proof pressure test, all tanks were bubble fluid leak checked with pure helium at 10 psig. The test setup is shown in Figure 40. The test procedure consists of pressurizing the tank to 10 psig and applying soap bubble compound to all welds and joints. No leakages were detected on either aluminum-or titanium-alloy tanks. The bubble fluid leak sensitivity is on the order of 1×10^{-5} scc/sec. No problems were encountered with the teflon seals used in place of the "MS" seals.

A hand sniffer probe leak check was conducted on all aluminum-alloy tanks prior to tank aging and hydrostatic test as a precautionary measure. The test was added to the program to provide maximum probability that no leaks through the welds would be detected after tank aging. Repairs after tank aging could have presented significant problems of overaging and reduced weld strength. Since the maximum single leakage rate specified was 1×10^{-7} scc/sec, the bubble fluid leak check was determined inadequate in terms of sensitivity (1×10^{-5} scc/sec). Weld defects in the range 1×10^{-5} to 1×10^{-7} scc/sec would have gone unnoticed until the final vacuum chamber leak, resulting in possible overaging of tanks after repairs.

The test setup consists of a Vecco leak detector with a hand sniffer probe (overall sensitivity range 1×10^{-6} to 1×10^{-7}).

The tanks were pressurized with helium to 20 psig then reduced to 15 psig prior to test. The tank hoop welds and cylinder longitudinal welds were then carefully checked for leaks. No leaks were detected. The Vecco detector sensitivity during the test was calibrated to a standard helium source to a sensitivity shown in Table XXIII.

4.3 HYDROSTATIC TEST

Each of the seven titanium alloy and six aluminum alloy tanks were subjected to hydrostatic proof test with demineralized water to verify structural integrity. The test setup schematic used is shown in Figure 41. The tube subassembly was installed on each end of the tanks with the teflon seals. The tanks were filled with demineralized water, then pressurized with helium to 150 psig (1.5 times the maximum operation pressure) and maintained at pressure for a minimum of 5 minutes, Figures 42 and 43.

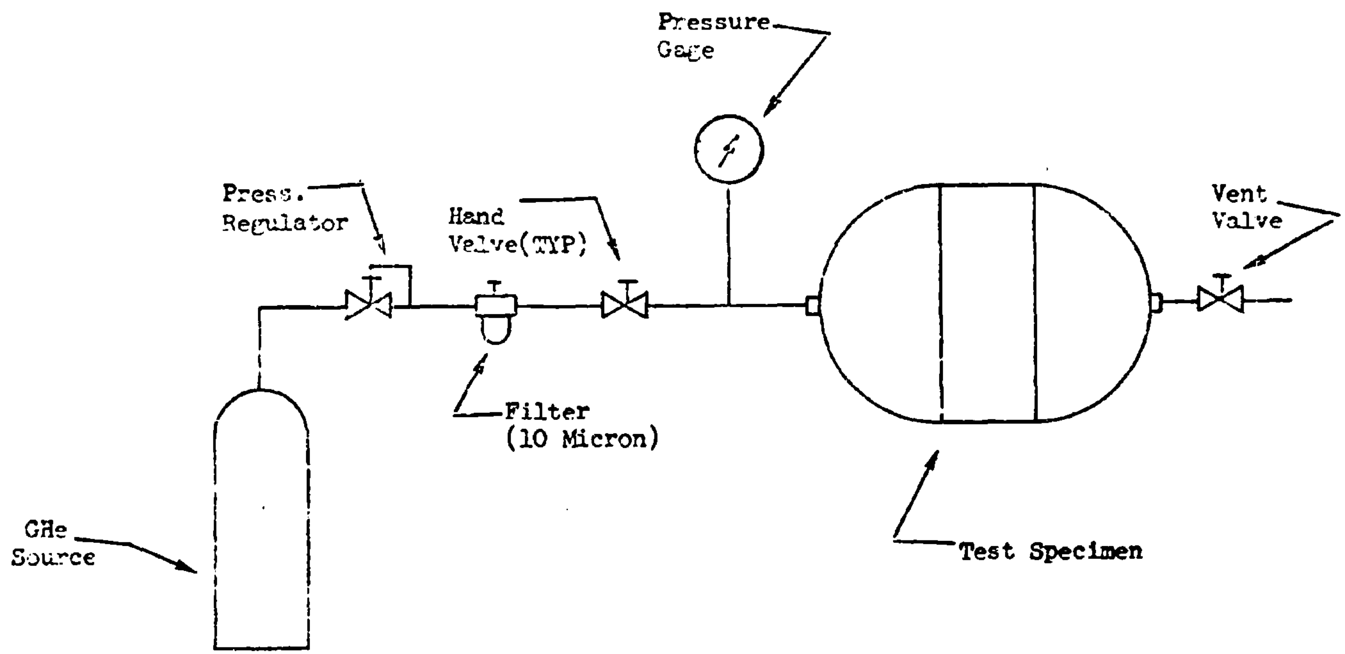


Figure 40. Schematic Pre-Proof Pressure Leak Test

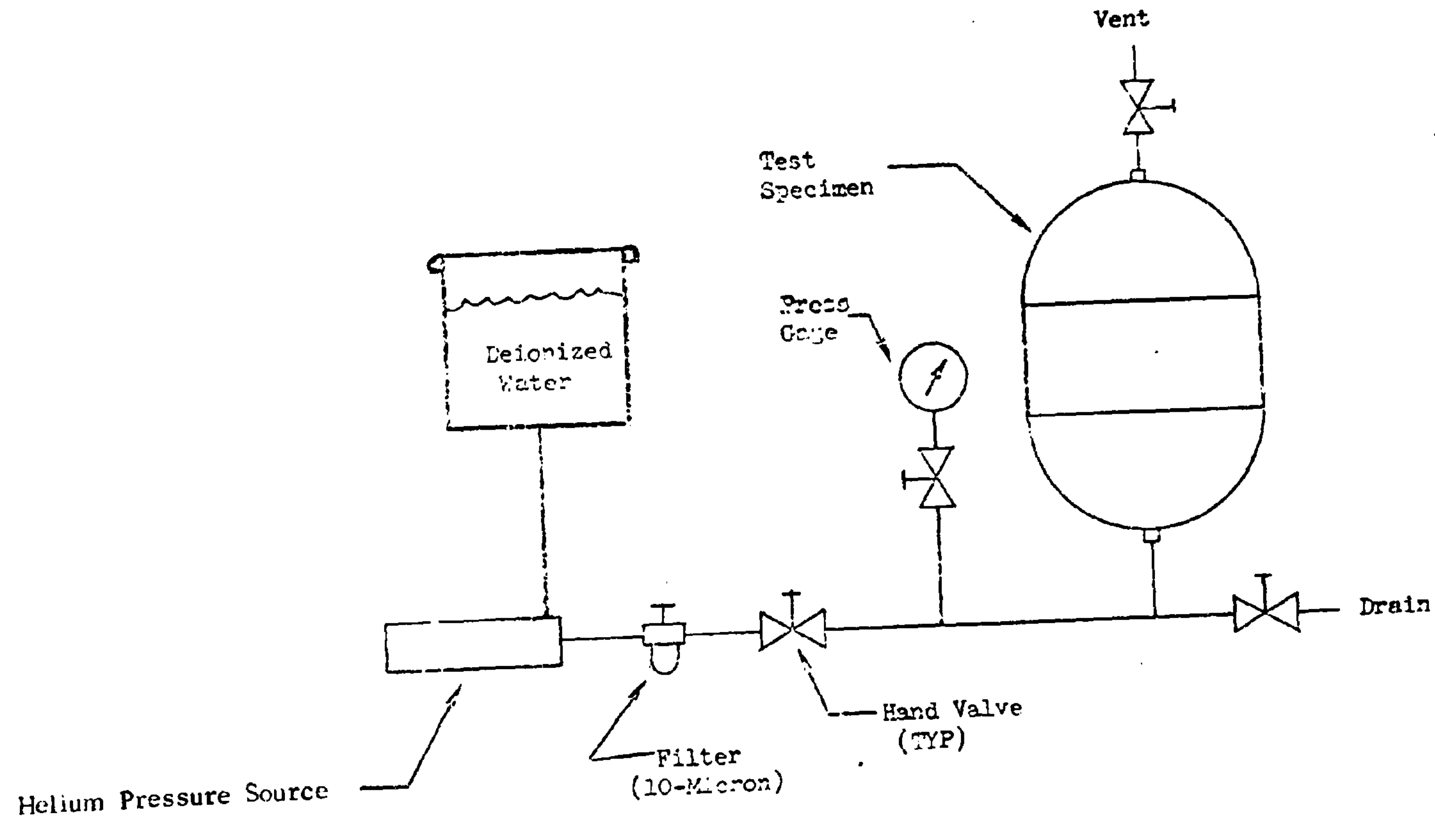


Figure 41. Proof Pressure Test Schematic

Figure 42. Proof Pressure Test Control Panel

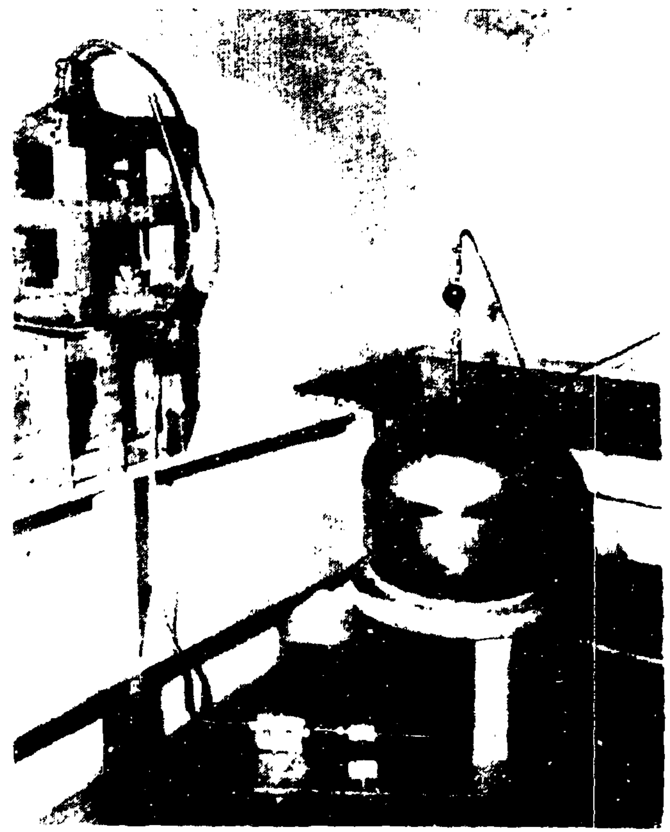


Figure 43. Proof Pressure Test Setup

Table XXIII. Hand Sniffer Probe Leak Check

Tank No.	Helium Detector Sensitivity (Std. Scc/Sec)	Leakage (Hoop & Long Cyl. Weld)
1	2.1×10^{-10}	None
2	$2\ 1 \times 10^{-10}$	None
3	2.1×10^{-10}	None
4	2.4×10^{-10}	None
5	2.0×10^{-10}	None
6	2.4×10^{-10}	None

Demineralized water was selected for these tests to reduce tank contamination and reduce mineral deposits that would form on the inside tank wall during the GN_2 tank drying operation.

All titanium-alloy tanks, except Tank 7, satisfactorily passed proof pressure tests. Tank 7 failed proof testing after approximately one minute at 150 psig. A cracking sound was heard, followed by a spray of water from the crack. Upon depressurization and inspection, a 1/2-inch by 1/4-inch T-shaped failure crack was noted along the hoop weld. The crack was initiated at a weld repair area. The failure was not catastrophic and can be repaired. However, since only six tanks were required for delivery under the contract, the tank was dried and set aside. A borescope was used to inspect the inside of the tank in the area of the crack. Inspection revealed that the failure appears to be the result of hydrogen/oxygen embrittlement from faulty weld repair. Although the tank was purged with helium prior to initiating weld repairs, completely satisfactory purging probably was not accomplished on this tank.

All aluminum alloy tanks met proof pressure requirements. The tests were routine with no unusual occurances.

All tanks were dried in a heated chamber at 200°F and purged with dry nitrogen for a period of 12 hours following the proof pressure test. A dew point reading was taken on the aluminum-alloy tanks to verify tank dryness.

No unusual difficulty was encountered in using the teflon seals in place of the standard "MS" seals. A minimum amount of torque was required to affect the seals. Only two seals were required in testing all tanks (two for the aluminum and two for the titanium tanks).

4.4 FINAL LEAK CHECK

The vacuum chamber leak-check method was used on all deliverable tanks. The test setup schematic is shown in Figure 44. The test was used to establish gross leakages and provide certification that no single leak through the tank welds is greater than 1×10^{-7} scc/sec. The test objectives were met on all deliverable tanks. No tanks required recycling through the factory for weld repairs and subsequent retest. All titanium tanks exceeded requirements. The delivered articles were tested to the maximum sensitivity of the system with no detectable leaks. No leaks were detected in three of the six aluminum alloy tanks delivered. Leakage was detected in the remaining three aluminum tanks. However, they were within the maximum allowable rates.

4.4.1 TITANIUM ALLOY TANK LEAK CHECK. The -45 stainless steel tank subassembly was installed on both ends of the 6Al-4V titanium alloy tanks with MS27855-08 seals. The tube subassemblies were installed per MS27850 using Kel-F lubricant on the back bearing surface of the plain flange and the threads of the threaded flange. The fittings were torqued to 490 to 565 inch-pounds. Torque paint was applied to the fittings to provide visual inspection of the fittings should loosening of the nut occur during handling. The tanks with the tube subassembly were then placed in the Convair Hi-VAC altitude chamber, pumped down to a chamber pressure of 1×10^{-4} Torr and individually leak checked. The test setup is shown in Figure 45. A Veeco leak detector, sensitive to a range of 3×10^{-10} scc/sec was used. All six tanks met the no leakage requirements of 1×10^{-7} scc/sec. Table XXIV indicates the system sensitivity to which each tank was tested.

Table XXIV. Titanium Tank Helium Leak Test Results

Tank No.	System Sensitivity (scc/sec)	Leakage
1	2.67×10^{-9}	None Detectable
2	3.0×10^{-9}	None Detectable
3	2.82×10^{-9}	None Detectable
4	2.67×10^{-9}	None Detectable
5	2.67×10^{-9}	None Detectable
6	2.67×10^{-9}	None Detectable

One minor problem was encountered during Tank 3 final leak test A leakage of 2×10^{-8} scc/sec was detected after approximately 15 minutes. The leakage progressively increased to approximately 1×10^{-6} scc/sec. The leakage could not be pinpointed. However, when all fittings in the system were retorqued it was found that the MS fitting torque had decreased from 490-565 inch-pounds to one-third of the prescribed torque.

A retest of the tank indicated no detectable leak to 2.82×10^{-9} scc/sec. All the remaining tanks were then retorqued to the prescribed value prior to installation in the vacuum chamber. Torque values decreased by one-half to one-third the initial torque indicating some relaxing and yielding of the seals in the interim. No further problems were encountered in the leak tests using this procedure.

4.4.2 ALUMINUM ALLOY TANK FINAL LEAK CHECKS. The -43 aluminum alloy fitting subassembly was installed on both ends of the X-2021 aluminum alloy tanks with MS27860-08 seals. The tube subassemblies were installed in accordance with the fitting installation specifications MS27850 using a Convair-developed lubricant, Spec 0-00777 Type II, on the bearing surfaces of the plain flange and the threads of the threaded fitting. Kel-F lubricant used on the titanium tanks was not used on the aluminum alloy tanks due to incompatibility of Kel-F with aluminum alloy. All fittings were torqued to the spec-recommended torque range of 280 to 320 inch-pounds.

Each of the six tanks with tubing subassemblies installed was leak checked in the Convair HIVAC attitude chamber using the same test procedure and setup as used on the titanium tanks. The tanks were pressurized to 100 psia with chamber pressure at 1×10^{-4} Torr using pure helium. A Veeco leak detector, sensitive to a range of 3×10^{-10} scc/sec was used to monitor leakages. The leakage rate was monitored for a minimum of 10 minutes at 100 psia. All six tanks successfully met the maximum leakage rate of 1×10^{-7} scc/sec. Table XXV presents the leakage rate and system sensitivity to which each tank was tested. Considerable difficulty was encountered in meeting the maximum leakage rate of 1×10^{-7} scc/sec on Tank 6. Initial vacuum leak check produced inconsistent results. Sporadic leakage was occurring over the test period. Readings of substantial leakages (2×10^{-6} scc/sec) followed by no detectable leakage and intermittent at one-minute intervals over a test period of 30 minutes. The test was stopped and the sniffer probe was used to isolate the leakage. Each of the end fittings were bagged to locate the leakage. It was determined that the leakage was occurring around the MS27860-08 seal. The fittings were retorqued and retested. Leakage continued to occur. The tank was then removed from the vacuum chamber and new seals were installed. Retesting revealed that leakage was still occurring, however, at a constant lower rate. The fittings were then torqued to 350 inch-pounds, or 30 inch-pounds above the recommended value. Subsequent test resulted in meeting the leakage requirements. Tank 6 was tested at pressure for a minimum of 15 minutes. A heat lamp was used to determine if a temperature change will increase the leakage. No increase was noted.

No difficulties were encountered in the leak check on the remaining five tanks. All test objectives were met on the initial setups.

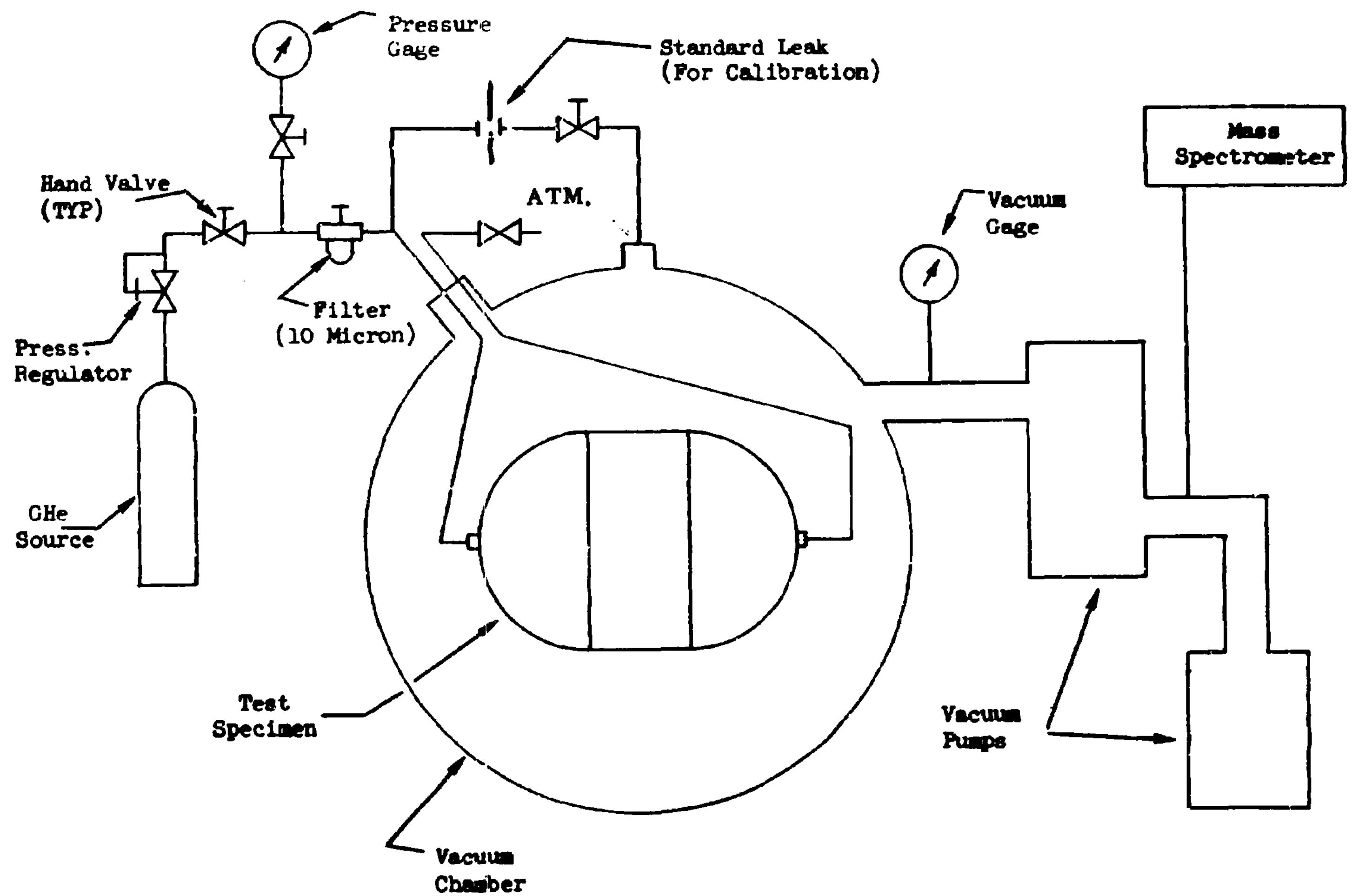


Figure 44. Schematic Vacuum Chamber Leak Check

Table XXV. Aluminum-Alloy Tank Helium Leak Test

Tank No.	System Sensitivity (Scc/Sec)	Leakage Rate (Max) (Scc/Sec)
1	1.4×10^{-9}	None detectable
2	1.5×10^{-9}	None detectable
3	2.0×10^{-9}	2.3×10^{-8}
4	1.6×10^{-9}	4.0×10^{-9}
5	2.0×10^{-9}	None detectable
6	1.5×10^{-9}	7.5×10^{-8}

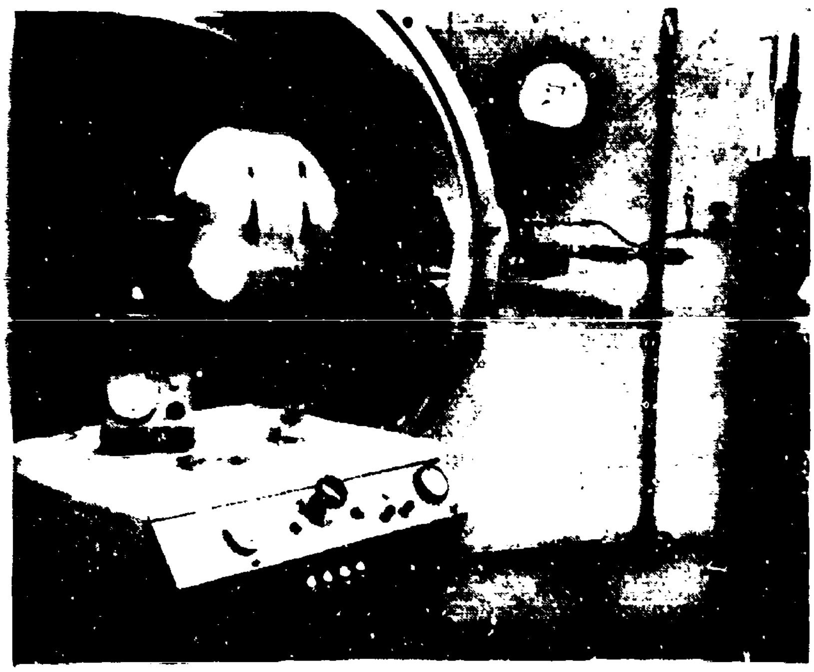


Figure 45. Vacuum Chamber Leak Test Setup

SECTION V

TANK CLEANING

Titanium Tanks 1, 2, and 4 were cleaned for hydrazine fuel and Tanks 3, 5, and 6 were cleaned for N_2O_4. Aluminum Tanks 2, 3, and 4 were cleaned for N_2O_4 and Tanks 1, 5, and 6 were cleaned for hydrazine. All tanks were then dried by purging with oil-free nitrogen to a dew point of -78°C. All openings were covered with a polyethylene film and sealed. The tanks were placed in a double-wall polyethylene bag with desiccant and sealed. Each tank was placed in a wooden shipping container lined with foam and processed for shipping.

5.1 TANK CLEANING FOR NITROGEN TETROXIDE (N_2O_4)

The following procedure was used to clean the titanium and aluminum-alloy tanks for use with nitrogen tetroxide (N_2O_4).

5.1.1 TITANIUM-ALLOY TANKS

a. Preparation

1. Inspect tank for rust, dirt, scale, etc.
2. Remove rust and scale mechanically or with a nitric acid/hydrofluoric acid mixture (5 parts 50% HF and 45 parts 50% HNO_3 to 50 parts H_2O).
3. Rinse until test indicates acid free.

b. Welds

1. Inspect inside of tank, especially welds. If welds are blackened, add a nitric acid/hydrofluoric acid mixture (enough to cover welds) for 30 minutes and rinse with clean water.
2. Inspect welds again. They must be scale-free; if they are still black, repeat Step a. If they are clean, rinse tank thoroughly with water, or steam it clean.

c. Cleaning

1. Rinse tank thoroughly with acetone.
2. Fill tank partially with 4-percent detergent solution previously heated to 65°C, and soak for 30 minutes.
3. Rinse tank thoroughly with deionized water.
4. For final rinse fill tank completely, and wash it thoroughly with deionized water.

5. Dry tank with oil-free nitrogen, and cover all openings with polyethylene film. At this step, the dew point of the tank atmosphere must be lower than -78°C.

5.1.2 ALUMINUM-ALLOY TANKS

a. Inspect tank interior and remove burrs, grease, dirt, scale, etc.

b. Cleaning

1. Degrease tank with trichloroethylene by soaking for 30 minutes.

2. Rinse with acetone.

3. Wash thoroughly with deionized water.

4. Add 4-percent aluminum cleaning solution (Turco Product 3266) for 20 minutes at room temperature. Cover the entire tank wall with the cleaning solution.

5. Wash tank thoroughly with water, or steam it clean. Inspect tank; it should be bright and clean.

6. The tank is dried by passing dry nitrogen gas through it. Dew point of the tank atmosphere must be lower than -78°C after the drying step.

7. Cover all openings with polyethylene film.

5.2 TANK CLEANING FOR HYDRAZINE FUELS

The following final cleaning procedure was used on the titanium and aluminum-alloy tanks for use with hydrazine fuels.

5.2.1 TITANIUM-ALLOY TANKS

a. Preparation

1. Inspect tank for rust, dirt, scale, etc.

2. Remove rust scale mechanically or with a nitric acid/hydrofluoric acid mixture (5 parts 50% HF and 45 parts HNO_3 to 50 parts H_2O).

3. Rinse until test indicates acid free.

b. Cleaning

1. Rinse tank thoroughly with ethyl alcohol.

2. Rinse tank thoroughly with deionized water.

3. Fill tank partially with 65°C, 4-percent detergent (Dreft or Tide) solution, and soak for 30 minutes rotating tank so that all surfaces are covered. Rinse with deionized water.

c. Welds

1. Inspect tank interior, especially welds. If welds are blackened add a nitric-acid/hydrofluoric-acid mixture (5 parts 50% HF and 45 parts HNO_3 to 50 parts H_2O) enough to cover welds, soak for 30 minutes, and rinse with deionized water.

2. Inspect welds again. If they are still black, repeat Step c.1. If they are clean, rinse tank thoroughly with deionized water.

d. Wash tank walls thoroughly with a 20-percent solution of ammonium hydroxide with a one hour soak.

e. Final Treatment

1. Wash tank thoroughly with deionized water.

2. Place tank in an oven at 110°C and dry tank with dry oil-free nitrogen gas purge until the dew point of the effluent gas is below -78°C. This step usually takes approximately 2-3 hours.

3. Finally, all openings to the tank are sealed, and it is ready for hydrazine fill.

5.2.2 ALUMINUM-ALLOY TANKS

a. Inspect tank interior and remove burrs, grease, dirt, scale, etc.

b. Cleaning

1. Degrease tank with trichloroethylene by soaking for 30 minutes. Rotate tank.

2. Rinse with alcohol.

3. Wash thoroughly with deionized water.

4. Add 4-percent aluminum cleaning solution (Turco Product 3266) for 20 minutes at ambient temperature. Rotate the tank so that the solution wets the entire tank wall.

5. Wash tank thoroughly with deionized water. Inspect tank; it should be bright and clean.

c. Fill the tank with 20-percent solution of ammonium hydroxide and permit this to stand for 1 hour.

d. Final Treatment.

1. Wask tank thoroughly with deionized water.

2. Place tank in an oven for 2-3 hours at 110°C and purge tank while in the oven with dry oil-free nitrogen until the dew point of the effluent gas is below -78°C.

3. Finally, all openings to the tank are sealed, and it is ready for hydrazine fill.

SECTION VI

CONCLUSIONS

The fabrication of thin-gage 6Al-4V titanium alloy and X-2021 aluminum alloy was successfully accomplished using the EB welding process. The weld process was a sound choice although the weld repair frequency was considerably higher than anticipated. Many of the weld problems can be attributed to the lack of internal tooling, although in the case of the 2021 aluminum alloy the material weldability is questioned.

The following conclusions and recommendations are a result of the fabrication, assembly and testing accomplished on this program.

1. The X-2021 aluminum alloy is not as weldable as 2219 as early reports indicated. The alloy is very sensitive to the amount of heat input in the welding operation and is susceptible to porosity and cracks without an adequate heat sink or chill bars. The maximum amount of filler wire is required while maintaining weld wire dilution to a minimum. The alloy could not successfully be EB or TIG repair welded when the minimum filler wire weld schedule was developed. Vaporization of cadimum and tin appears to be the problem although more development and testing is required on the welds.

2. The 2021 aluminum alloy in the solution heat treated condition has superior formability qualities over 2219 and 6061 in the same conditions. The 30-31 percent elongation versus 22 percent for 2219 is significant in forming. The long natural aging rate is also beneficial from the manufacturing standpoint. It allows sufficient time between solution heat treat and forming without age hardening. The initial difficulties encountered in the hydroforming in the solution heat treated conditions are normal in developing the proper hydroform schedule. Had sufficient material been available from the mill no difficulties would have been encountered in producing production quality bulkheads in the desired quantity.

3. EB welding of titanium on the initial pass is preferred. The vacuum environment assures no hydrogen or oxygen embrittlement during welding. The TIG welding is preferred for weld repairs. Small or short defects can be more readily repaired by TIG welding. EB repair welds would result in a repair several inches long.

4. EB welding of the small diameter aluminum-alloy tubing is not recommended. The low heat input required in aluminum-alloy welding necessitates a high welding rate. For the 6061-T6 tube subassembly welds, the rate of over 100 ipm resulted in a higher weld defect rate. Weld repairs were accomplished by TIG.

5. The step-by-step weld leak-check approach used during this tankage program is recommended to detect leakage or defective welds as early in the tank assembly as possible. Weld repairs are simplified and detection of leakage in the final assembly can more readily be established. This is particularly true when a high leak-check sensitivity is achieved in each step of the leak-check procedure.

6. The Veeco hand detector or vacuum chamber leak-check is recommended prior to tank aging for aluminum-alloy tanks that are to be aged prior to delivery. A good leak check is required prior to aging to preclude repair welds after aging.

7. The teflon washers used in place of the MS 27855-08 and MS 27860-08 metal seals during the proof pressure and preliminary leak checks were highly successful and resulted in considerable cost savings. But teflon seal should not be re-used in any helium leak checks as a result of the background helium from absorptions into the teflon. The metal seals when torqued to the recommended values tend to relax by as much as 30 to 50 percent of the initial torque when left for any length of time. Retorquing is required prior to final leak checks.

SECTION VII

REFERENCES

1. Air Force Contract F04611-68-C-0052, " Package System Storability Test Articles," dated 26 February 1968.

2. A. Hucknall and J. G. Willis, "Design and Manufacture of Fifteen-Gallon Propellant Vessels for Tank Storability Program," AFRPL-TR-66-35, Air Force Contract AF04611-10793.

3. R. V. Turley, et. al., "Stress Corrosion Susceptibility of Welded Aluminum Alloys," AFML-TR-67-293, August 1967.

4. "Titanium for the Chemical Engineer," DMIC Memorandum 234, 1 April 1967.

5. R. A. Schultz, "Alcoa Aluminum Alloy 2021" Alcoa Green Letter dated April 1968.

6. R. A. Schultz, "Alcoa Aluminum Alloy 2021" proposed Alcoa Green Letter dated January 1968.

7. R. W. Westerlund, et. al., "Development of a High Strength Aluminum Alloy," Contract No. NAS 8-5452 dated 4 April 1967.

APPENDIX I

PROPELLANT TANK STRESS ANALYSIS

SYMBOLS

a	Radius, in., semi-major axis, in.
b	Semi-minor axis, in.
F_{tu}	Allowable tension ultimate stress, psi.
F_{ty}	Allowable tension yield stress, psi.
f_t	Applied tension stress, psi.
f_1	Meridional stress, psi.
f_2	Hoop stress, psi.
M. S.	Margin of safety
N_1	Meridional normal force, lb/in.
N_2	Hoop normal force, lb./in.
P	Internal pressure, psi.
R_1	Meridional radius of curvature, in.
R_2	Hoop radius of curvature, in.

MATERIAL ALLOWABLES

1. X2021-T62 Aluminum Alloy

   F_{tu} = 67,000 psi
   F_{ty} = 57,000 psi — GDC Spec 0-00868

   Solution Heat Treat - Weld + Age

   F_{tu} = 40,300 psi
   F_{ty} = 34,500 psi — See Note (1)

2. 6Al-4V Titanium Alloy

   F_{tu} = 130,000 psi
   F_{ty} = 120,000 psi — Ref. MIL-T-9046 Anl., Type III Comp. D $<.250$

   As welded - Annealed + weld

   F_{tu} = 117,000 psi
   F_{ty} = 108,000 psi — See Note (2)

NOTE: (1) Based on a conservative weld efficiency of 60%

(2) Based on weld efficienty of 90%

MATERIAL AND THICKNESS

Material	Material Condition	Thickness (Inches)
1. X-2021-T62	Post-weld artificially aged (A)	.064
2. 6Al-4V Titanium	Annealed + weld	.040

CYLINDER SECTION

Aluminum Alloy Burst Strength

$$f_t \text{ hoop} = \frac{PR}{t} = \frac{200 \times 9}{.064} = 28,100 \text{ psi Ult.}$$

$$f_t \text{ meridional} = \frac{PR}{2t} = \frac{200 \times 9}{2 \times .064} = 14,050 \text{ psi Ult.}$$

Titanium Alloy Burst Strength

$$f_t \text{ hoop} = \frac{PR}{t} = \frac{200 \times 9}{.040} = 45,000 \text{ psi Ult.}$$

$$f_t \text{ meridional} = \frac{PR}{2t} = \frac{200 \times 9}{2 \times .040} = 22,500 \text{ psi Ult.}$$

Aluminum Alloy Stress at Operating Pressure

$$f_t \text{ hoop} = \frac{PR}{t} = \frac{100 \times 9}{.064} = 14,050 \text{ psi}$$

$$f_t \text{ meridional} = \frac{PR}{2t} = \frac{100 \times 9}{2 \times .064} = 7,025 \text{ psi}$$

Titanium Alloy Stress at Operating Pressure

$$f_t \text{ hoop} = \frac{PR}{t} = \frac{100 \times 9}{.040} = 22,500 \text{ psi}$$

$$f_t \text{ meridional} = \frac{PR}{2t} = \frac{100 \times 9}{2 \times .040} = 11,250 \text{ psi}$$

MARGIN OF SAFETY CYLINDER SECTION

Aluminum Alloy Base Material

$$M.S. = \frac{F}{f} - 1 = \frac{67{,}000}{28{,}100} - 1 = +1.37$$

Aluminum Alloy Longitudinal Weld Joint

$$M.S. = \frac{F}{f} - 1 = \frac{40{,}300}{28{,}100} - 1 = +.43$$

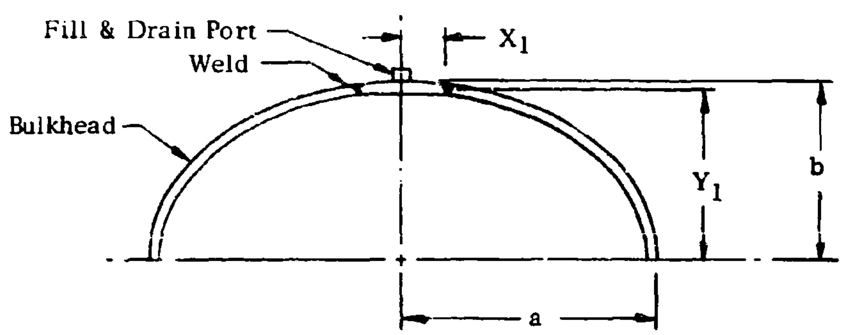
Titanium Alloy Base Material

$$M.S. = \frac{F}{f} - 1 = \frac{130{,}000}{45{,}000} - 1 = +1.89$$

Titanium Alloy Longitudinal Weld Joint

$$M.S. = \frac{F}{f} - 1 = \frac{117{,}000}{45{,}000} - 1 = +1.60$$

ELLIPSOIDAL HEADS (-17Aluminum and -7 Titanium)



Hoop Load/in.

$$N_2 = \frac{PR_2}{2} \left[2 - \frac{R_2}{R_1} \right]$$

Meridional Load

$$N_1 = \frac{PR_2}{2}$$

Where $R_1 = R_2^3 \frac{b^2}{a^4}$, $\quad R_2 = \frac{\left[a^4 y^2 + b^4 x^2 \right]^{1/2}}{b^2}$

ELLIPSOIDAL HEADS (Weld Around End Closure)

$$X_1 = 1.25 \qquad Y_1 = \frac{b}{a}\left(a^2 - x^2\right)^{1/2}$$

Where $a = 9.00,\ b = 6.35$

$$Y_1 = .7056\ (81.00 - 1.56)^{1/2} = 6.2878$$

$$R_2 = \left[\frac{(9)^4\ (6.29)^2 + (6.35)^4\ (1.25)^2}{(6.35)^2}\right]^{1/2} = 12.7 \text{ inches}$$

$$R_1 = R_2^3\ \frac{b^2}{a^4} = (12.7)^3\ \frac{(6.35)^2}{(9)^4} = 12.60 \text{ inches}$$

Hoop Load at Burst Pressure

$$N_2 = \frac{PR_2}{2}\left[2 - \frac{R_2}{R_1}\right] = \frac{(200)(12.7)}{2}\left[2 - \frac{12.7}{12.6}\right] = 1260 \text{ lb/in.}$$

Meridional Load at Burst Pressure

$$N_1 = \frac{PR_2}{2} = \frac{200 \times 12.7}{2} = 1270 \text{ lb/in.}$$

Maximum bulkhead stress at weld of fill and drain port.

For Aluminum Alloy

$$f_1 = \frac{N_1}{t} = \frac{1270}{.064} = 19,900 \text{ psi}$$

For Titanium Alloy

$$f_1 = \frac{N_1}{t} = \frac{1270}{.040} = 31,750 \text{ psi}$$

MARGIN OF SAFETY (Bulkhead Weld, Fill and Drain Port)

For Aluminum Alloy

$$M.S. = \frac{F}{f} - 1 = \frac{40,300}{19,900} = +1.02$$

For Titanium Alloy

$$M.S. = \frac{F}{f} - 1 = \frac{117,000}{31,750} - 1 = +2.69$$

Discontinuity stresses in circumferential joint between cyliudrical section and ellipsoidal head.

STRESS CONCENTRATION FACTORS FOR ELLIPSOID TO CYLINDER

$$\frac{b}{a} = \frac{6.35}{9.00} = .706$$

$$\frac{f^*_{hoop}}{f_{hoop}} = 1.068$$

Ref. Timoshenko, "Theory of Plates and Shells"

* Includes discontinunity effects

$$\frac{f^*_{meridional}}{f_{hoop}} = .794$$

For Aluminum Alloy Tanks

$$f^*_{t\ hoop} = 1.068\ f_{hoop} = 1.068 \times 28,100 = 30,100 \text{ psi Ult.}$$

$$M.S. = \frac{F}{f} - 1 = \frac{40,300}{30,100} - 1 = +.34$$

For Titanium Alloy Tanks

$$^*f_{t\ hoop} = 1.068\ f_{hoop} = 1.068 \times 45,000 = 48,100 \text{ psi Ult.}$$

$$M.S. = \frac{F}{f} - 1 = \frac{117,000}{48,100} - 1 = +1.43$$

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APPENDIX II

PROCESS SPECIFICATIONS FOR PACKAGE SYSTEM STORABILITY TEST ARTICLES

This appendix comprises the following Convair divsion specifications for the manufacture of 15-gallon tanks under this program:

- Manufacturing Specifications
- Material Identification and Utilization
- Hydrostatic Test and Leak Check
- Cleaning and Passivation
- Engineering Specifications

The specification list includes manufacturing and processing documents which control material acceptance, coupons, fabrication, quality control, testing, cleaning for passivation and packaging of the 15-gallon capacity propellant vessels. As the vessels are fabricated from two different materials, this manufacturing specification index is subdivided into two sections, each one of which lists all manufacturing documents and engineering specifications that define the engineering requirements for this program.

SPECIFICATION INDEX FOR PACKAGE SYSTEM STORABILITY TEST

SECTION I. 6Al-4V Titanium Alloy Tanks
SECTION II. X-2021 Aluminum Alloy Tanks

SECTION I. 6Al-4V Titanium Alloy Tanks

	Material Specification	Manufacturing Requirement	Engineering Requirements
A.	**Material Specification**	**Manufacturing Requirement**	**Engineering Requirements**
	1. Sheet Stock	GDC Rel. Cont. Dept Inst. 3321	MIL-T-9046F Type III Comp. D
	2. Bar Stock		MIL-T-9047D Type III Comp. A
	3. Weld Wire/Rod		GDC 0-00813-2 or ASTM B382 Class ERT1-6Al-4V
B.	**Material Identification and Utilization**		
	1. Identification	MOS 1-02629-001, MPCS 1-02631	GDC PSSTA-001, 68-59788, MIL-STD-130
	2. Utilization	Operations & mfg. plan P. E. 68-400-14 & 68-59788	GDC PSSTA-001
C.	**Material Handling/ Packaging**		
	1. Sheet Metal & Plate, Raw Stock	H/PS 1-00088	-
	2. Sheet Metal Formed Parts	H/PS 1-00067	-
	3. Machined & Threaded Parts	H/PS 1-00110	-
	4. Tank Packaging	H/PS GDC 65-0047	Fed Spec PPP-B-601 & MIL-P-116

D. Forming & Machining Operation

1. Detail parts fabrication to be controlled by Engineering Drawing 68-59788, Operations & Mfg Plan P. E. 68-400-14 and factory planning as applicable.

E.	**Cleaning Operation**		
	1. Commercial Clean	MOS 1-02827	GDC 0-75092
	2. Pre-weld	MOS 1-02598	
	3. Process Control	MPCS 1-02543	

SECTION I. 6Al-4V Titanium Alloy Tanks (cont'd)

		Manufacturing Requirement	Engineering Requirements
F.	Heat Treatment		
	1. Annealing	MPS 50.05C	MIL-H-81200 & GDC 0-75171
	2. Stress Relieving	MPS 50.05C	MIL-H-81200 & GDC 0-75171
G.	Welding		
	1. EB Welding	MS 42.18	GDC 0-75048
	2. Certification	MPCS 1-02784	MIL-T-5021
H.	Inspecting		
	1. Penetrant Inspection	MPCS 1-02715	MIL-I-6866, GDC 0-75174-2 or -3
	2. Radiographic Inspec.	MS 27.41	MIL STD 453, GDC 0-75115 NAS 1514 Class II
I.	Tank Testing		
	1. Leak Testing, Bubble Fluid	MS 26.01 A	GDC 64A6050
	2. Hydrostatic Test	--	GDC 64A6050
	3. Helium Leak Tests	--	GDC 64A6050
J.	Final Cleaning and Passivation		
	1. Oxidizers	--	GDC 68-59801, GDC 572-3-68-52
	2. Hydrazine Fuels	--	GDC 68-59801, GDC 572-3-68-53

SECTION II. X-2021 Aluminum Alloy Tanks

	Material Specification	Manufacturing Requirement	Engineering Requirements
A.	**Material Specification**	**Manufacturing Requirement**	**Engineering Requirements**
	1. Sheet and Plate	GDC Rel. Cont. Dept. Inst. 3321	GDC 0-00868
	2. Weld Wire/Rod(2319)	" " "	GDC 0-00810-2 or Fed Spec. QQ-R-566
B.	**Material Identification and Utilization**		
	1. Identification	MOS 1-02629, MPCS 1-02631	GDC PSSTA-001, 68-59788, MIL-STD 130
	2. Utilization	Operations & Mfg Plan P. E. 68-400-14 & 68-59788	GDC PSSTA-001
C.	**Material Handling/ Packaging**		
	1. Sheet Metal & Plate Stock	H/PS 1-00088	
	2. Sheet Metal Formed Parts	H/PS 1-00067	
	3. Machined & Threaded Parts	H/PS 1-00110	
	4. Tank Packaging	H/PS GDC 65-0047	Fed Spec PPP-B-601 & MIL-P-116

D. **Forming & Machining Operation**

1. Detail parts fabrication to be controlled by Engineering Drawing 68-59788. Operations and Mfg. Plan P. E. 68-400-14 and factory planning as applicable.

E.	**Cleaning Operation**		
	1. Commercia ean	MOS 1-02827	GDC 0-75092
	2. Pre-we	MS 61.07	
	3. Proces	MPCS 1-02543	
F.	**Heat Treatment**		
	1. Solution Heat Treat	MOS 1-02693-001	GDC 0-75168 & MIL-H-6088D
	2. Annealing & Stress Relieving	MOS 1-02693-002	as modified by Eng'g. Dwg. 68-59788
	3. Aging	MOS 1-02693-003	" " "
	4. Controlling Al. Aly. Heat Treatment	MPCS 1-02694	" " "
	5. Controlling Temp.	MPCS 1-02678	" " "

SECTION II. X-2021 Aluminum Alloy Tanks (cont'd)

		Manufacturing Requirement	Engineering Requirements
G.	Welding		
	1. EB Welding	MS 42.18	MIL-W-8604 & GDC 0-75048
	2. Certification	MPCS 1-02784	
H.	Inspecting		
	1. Penetrant Inspection	MPCS 1-02715	MIL-I-6866 Type II & GDC 0-75174
	2. Radiographic Inspec.	MS 27.41	MIL-STD 453 & GDC 0-75115 MIL-R-4577 Class 2
I.	Tank Testing		
	1. Leak Testing, Bubble Fluid	MS 26.01A	GDC 64A6050
	2. Hydrostatic Test	--	GDC 64A6050
	3. Helium Leak Test	--	GDC 64A6050
J.	Final Clean and Passivation		
	1. Oxidizers	--	GDC 68-59801, GDC 572-3-68-52
	2. Fuels	--	GDC 68-59801, GDC 572-3-68-53

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11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY Air Force Rocket Propulsion Laboratory Research and Technology Division Air Force Systems Command Edwards Air Force Base, California

13 ABSTRACT

This report presents the design, manufacture, testing, and delivery of 15-gallon tanks for subsequent use by the Air Force Rocket Propulsion Laboratory in their long-term propellant tankage storability program. A total of 12 tanks, 6 each of materials 6Al-4V ELI titanium alloy and X-2021-T62 aluminum alloy, was delivered to the Air Force Rocket Propulsion Laboratory. Six tanks, three of each material, were cleaned for nitrogen tetroxide (N_2O_4) and the remaining six were cleaned for hydrazine propellant testing. Tensile coupons, both welded and unwelded, from each sheet material used in the tank fabrication were delivered to assist in correlating vessel storability performance. The tank configuration, consisting of two ellipsoidal bulkheads ($a/b = \sqrt{2}$), is 18 inches in diameter with a cylinder length of 5.4 inches and includes an inlet and outlet for propellant loading, pressurization, and draining. The tanks were designed for an operating pressure of 100 psig with a minimum factor of safety of 1.5 based on yield. Fabrication processing, including welding, quality control, inspection requirements, and proof testing, was representative of actual production tank processing. Tank welding was accomplished by electron beam (EB) welding.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Tank Fabrication (U)						
Storable Propellant Tanks (U)						
6Al-4V Titanium-Alloy Tank (U)						
X-2021 Aluminum-Alloy Tanks (U)						
Welding Process (U)						
Storability (U)						

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